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EDUCATION

ANALYSES and RECOMMENDATIONS related to PUBLIC SCHOOL CONSTRUCTION

BUREAU of RESEARCH
COLLEGE of ARCHITECTURE
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ANALYSES AND RECOMMENDATIONS
RELATED TO PUBLIC SCHOOL CONSTRUCTION

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THE OFFICE OF EDUCATIONAL FACILITIES CONSTRUCTION
FLORIDA DEPARTMENT OF EDUCATION

submitted by

THE BUREAU OF RESEARCH
COLLEGE OF ARCHITECTURE
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ANALYSES AND RECOMMENDATIONS

RELATED TO PUBLIC SCHOOL CONSTRUCTION

INTRODUCTION

Following a number of meetings and discussions with the Office of Educational Facilities, Florida Department of Education, the Bureau of Research, a unit in the College of Architecture, University of Florida, entered into an agreement to conduct studies on a number of subjects related to the construction of school facilities.

The subjects as outlined in the agreement are as follows:

- Establishment of prototype design criteria related to mechanical, electrical, lighting, plumbing, heating, air-conditioning and ventilating systems

- Reorganization and revisions of Regulations, Chapter 6A-2, Educational Facilities Construction

- Development of a process and procedure for determining life cycle costs for school buildings

- Development of procedures to be used in determining the most feasible and financially acceptable methods in bidding construction projects

- Enumeration of advantages and disadvantages of various bidding procedures and preparation of charts showing sequence of events and responsibilities.

- Development of a plan for adapting solar energy to educational facilities.

These subjects have been re-arranged in this report under the following headings:

Section I: Design Criteria and Energy Conservation

Section II: Life Cycle Costing for Educational Facilities

Section III: Recommended Revisions to Chapter 6A-2, Educational Facilities Construction

Section IV: Alternative Bidding/Building Procedures

Section V: Plan for Development of Solar Energy Utilization in Florida Schools

Section VI: Recommendations for Further Studies

On the assumption that the report may be separated for purposes of review and discussion, each section has its own Table of Contents, Introduction, Discussion, Recommendations, References and Appendix. In addition, several documents that were included as appendices in the progress reports are now bound under separate cover.

The broad scope and complexity of the subjects related to the time available (approximately 7 months study time, 1 man-year of effort) established the approach to the study.

The final report is based on literature search, interviews, meetings with Office of Educational Facilities staff and numerous in-house meetings and reviews by the investigating group. No attempt was made to conduct "hard" research, testing, observations, etc.

It should be noted that the references cited in the report are those having direct bearing on discussions and recommendations; they are not intended to be a comprehensive listing of all the material reviewed or available.

A limited number of interviews were conducted by the investigators that proved to be valuable in verifying the current state-of-the-art and trends related to the areas of investigation. These included

nationally known construction management firms, key personnel in federal agencies and representatives at the school district level.

Meetings with the Office of Educational Facilities staff proved to be most helpful in clarifying the role of that office and in pinpointing a number of specific problems requiring more detailed review and clarification.

Finally, the investigating group had numerous informal meetings, discussions and review sessions that provided valuable feedback on the various portions of the study.

The purpose of the report as perceived by the investigators is threefold:

(1) provide the staff of the Office of Educational Facilities with background information and references pertinent to the identified subject areas.

(2) provide an overview of the 'state-of-the-art' through written discussions and interpretations of the material reviewed.

(3) make recommendations and/or suggestions to the Office of Educational Facilities for their use in developing future directions and policies affecting school building and operating procedures in Florida.

Several observations must be made concerning the subjects addressed in the report:

All of the subjects addressed relate directly to the issue of economy and efficiency in the building process;

Almost all of the subjects relate directly to the issue of energy utilization in buildings.

"Issues" can seldom be reduced to simple questions and finite, permanent answers. The subjects covered in this report are no exception; the best answers today should be replaced by better answers tomorrow. It is believed that these answers can only be attained through concentrated research, application and observation of results in real situations. Literature searches are valuable in understanding the past and the present but do not often provide directions in times of rapid change. For this reason, a brief listing of recommendations for future studies is listed in the final section of this report. It is hoped that some of these will lead to further investigation and ultimately application.

ACKNOWLEDGEMENTS

The wide diversity of subject matter involved in this report necessitated a "team" approach to the study. The Bureau of Research was fortunate in being able to obtain the services of exceptionally well-qualified consultants and faculty.

Clark W. Pennington was the prime contributor to the subjects of design criteria and solar applications. He was ably supported by Robert Mizell, Graduate Assistant, who carried out an extensive literature search under the direction of Mr. Pennington. J. W. Griffith acted as the prime consultant and contributed valuable data on life-cycle cost analysis as well as contributing recommendations on lighting. Tony White assumed the responsibility of developing the final document on life-cycle costing and assisted in overall coordination of the project. Gordon Yager was responsible for the section on bidding/building procedures.

Appreciation is also expressed for the assistance and advice of the Office of Educational Facilities staff and the many individuals from the public and private sector who were most cooperative in contributing their time and knowledge to the project. Finally, thanks are due Carolyn Carter for her invaluable assistance in organizing and producing the final report.

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ANALYSES AND RECOMMENDATIONS

RELATED TO PUBLIC SCHOOL CONSTRUCTION

LIST OF SECTIONS

Section I - DESIGN CRITERIA AND ENERGY CONSERVATION

Section II - LIFE CYCLE COSTING FOR EDUCATIONAL FACILITIES

Section III - RECOMMENDED REVISIONS TO CHAPTER 6A-2, EDUCATIONAL FACILITIES CONSTRUCTION

Section IV - ALTERNATIVE BIDDING/BUILDING PROCEDURES

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ANALYSES AND RECOMMENDATIONS

RELATED TO PUBLIC SCHOOL CONSTRUCTION

Section I - DESIGN CRITERIA AND ENERGY CONSERVATION

DESIGN CRITERIA AND ENERGY CONSERVATION

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INTRODUCTION

This section combines two of the major subject areas originally identified for this study. Part of the objectives stated initially were to "establish Prototype Design Criteria" for HVAC, plumbing, electrical, etc., and to develop "Energy Conservation Requirements..."

At the outset, an attempt was made to treat these as two separate and distinct subjects leading to different sets of recommendations. As the study progressed it became increasingly apparent that these subjects were so closely related that any attempt to separate them would only result in confusion or redundance.

A second concern that developed during the study involved the terminology used in the original format. The first of these is use of the word "Prototype". In the building world, the term is generally used to describe a "one of a kind" building. The recommendations contained in this section are intended to apply to all educational facilities; accordingly, the term 'prototype' has been dropped to avoid confusion. This should not be construed as suggesting that the development of prototype facilities is not feasible. A principal recommendation in Section VI deals with prototypes as research vehicles.

It should also be noted that recommendations related to Energy Conservation are identified as Guidelines. By definition the word "conservation" involves "the <u>act</u> of preserving or protecting," as in "the conservation of forests, harbors, etc." In this case the issue involves the act of conserving energy. It is important to note that the <u>potential</u> for conserving energy is established at the design stage;

the conservation of energy will result from intelligent and efficient operation and maintenance of the school plant. Establishing 'rules' or 'requirements' for operation and maintenance will not insure energy conservation.

The section is divided into two parts; Part I, Design Criteria, includes a recommendation to establish requirements for the design of HVAC primarily (but not exclusively) related to new buildings. Part II, Energy Conservation, recommends the establishment of guidelines for conserving energy in existing buildings.

PART I: DESIGN CRITERIA

It is recommended that ASHRAE Standard 90-75 be adopted as minimum design requirements necessary to improve energy utilization in educational facilities.

ASHRAE Standard 90-75, Energy Conservation in New Building Design, considers all the forms of energy consumed within the building boundary relating to heating, ventilation, air conditioning, lighting, and electrical power distribution. Work on this Standard was initiated in 1973 at the suggestion of the National Conference of States on Building Codes and Standards (NCSBCS). At that time a standard for the same purpose was in preparation by the National Bureau of Standards. ASHRAE was asked to build on this and develop a consensus standard which would be practical and acceptable, and set minimum requirements for energy conservation in new buildings. The standard was approved by ASHRAE in August, 1975, and has already been adopted by a number of states.

The standard covers the following areas of building design:

a. The Exterior Envelope

b. HVAC Systems

c. HVAC Equipment

d. Service Water Heating

e. Electrical Distribution Systems

f. Lighting Power Budget

After establishing an energy budget for the building, it provides for full flexibility by allowing alternate designs which do not exceed this budget in annual usage. Further, it provides that where non-depleting sources such as solar or wind power are used, the budget can be increased by the amount these provide.

The standard is to be revised annually for the next few years, to improve and refine it. It will soon have added to it a chapter on comparison of energy sources.

The following 9 topics are referenced to specific paragraphs in ASHRAE Standard 90-75; these are intended as more detailed discussions of the stated requirements.

1. "U" Values for Walls and Roofs.

Refer to 4.3.4.1 and 4.3.2 through 4.4.3.2, ASHRAE Standard 90-75

A precise optimum value would be dependent upon cost of the insulation vs. the cost of energy, and so would be constantly changing. A maximum which is reasonable and acceptable can be arrived at. Conformance with the new ASHRAE Standard 90-75 should be accepted as a minimum requirement.

For most of the Florida area 90-75 requires a maximum "U" value for roofs or combined roof and ceiling of 0.12, for either heating or cooling. It should be noted that this is a weighted average value, and so includes the effect of any areas of high heat loss or heat gain, such as skylights.

For walls, for heating only, 90-75 permits a "U" value of 0.45. Again, it should be noted that this is a weighted average, and includes both opaque walls and window areas. If the "U" factor for the opaque wall area is 0.35, and windows are single clear glass, then not more than 13% of the wall area could be glass.

For wall areas in air conditioned buildings no "U" value is specified. Instead, a maximum allowable heat gain per square foot per hour is indicated. This for the mid-Florida area is given as 30 BTU/hr.ft.^{2} This performance type requirement has some advantage in allowing latitude to the architect, while at the same time limiting energy requirements. For totally enclosed schools a figure considerably below that specified should be possible.

The DGS Florida Energy Conservation Manual lists "U" values of 0.10 for roofs and ceiling and 0.15 to 0.11 for walls, with window areas limited to 35% of total wall area, as the maximum allowable.

In view of the above, the "U" values specified in 6A-2.67(1) of 0.075 for roof areas appears adequate, provided an overall "U_o" value of 0.12 is also specified.

The value of 0.35 for exterior wall areas exclusive of glass areas should be supplemented with an overall heat gain restriction of not more than 30 BTU/hr.ft.^{2} This would serve either to limit glass areas, or require proper treatment to reduce heat gain through fenestration areas.

2. Design Conditions

Refer to 4.2.5, 5.3.2.1 and 5.3.2.2. of ASHRAE Standard 90-75

Indoor design conditions as outlined in paragraph 6A-2.63 are in agreement with DGS Florida Energy Conservation Manual (ref. 2) and other recognized comfort standards, and so appear to be acceptable. There is, however, some question concerning outdoor conditions to be used for load calculation purposes.

The DGS Florida Energy Conservation Manual Provides a Florida Regional Map (p. 58) which divides the state into eight regions, and lists for each winter and summer design temperatures. These are taken from the 1972 ASHRAE "Handbook of Fundamentals". The winter design temperatures are from the 97½% column, while the summer design temperatures are taken from the 2½% column. For the winter design condition, the 97½% column lists temperatures which are equaled or exceeded in the months of December, January, and February 97½% of the time. For the summer design condition, the 2½% column lists temperatures which are not equaled or exceeded more than 2½% of the time during the months of June, July, August, and September.

Three alternatives appear feasible here. One is to adopt the DGS Florida Energy Conservation Map and design temperatures. This appears to be the most feasible. The second alternative would be to adopt the map and winter design temperatures, but list summer design temperatures from the 5% column of the ASHRAE Handbook. This would result in a somewhat smaller design cooling load. The third alternative

would be to specify that outdoor design temperatures be taken from the 97½% and either 2½% or 5% column of the ASHRAE Handbook. Where conditions are not listed in the Handbook, they could be determined by interpolation between places which are listed.

A possible reason for using the 5% rather than the 2½% column is that schools are frequently not occupied between June 15 and August 15. This does not appear valid, since the hottest and most humid weather often occurs in late August and September. A study to determine what the design summer dry and wet bulb temperatures would be, based on the period June 1 to 15 and August 15 to September 30 could be made from data available from the U. S. Weather Bureau; however, such a study would be expensive and of doubtful value since many schools are now going to year-round operation.

A study of the weather data in the ASHRAE Handbook indicates that going from the 2½% to the 5% column lowers both the dry bulb and wet bulb temperatures by 1^{o}F for most of Florida. This would provide about a 12% reduction in the calculated latent ventilation load and would provide some reduction in the calculated sensible heat gain through the shell of the structure. The extent of this is less clearly defined , as it is affected by solar effects, the mass of the structure, and the load calculation method employed. There would be no reduction in internal loads due to people, lights, equipment, etc.

An overall reduction in total cooling load of between 3 and 7 percent might be expected. This appears to be below the confidence level of the load calculation method itself. It is recommended that the 2½% columns be used, but permit selection of equipment which comes

within 5% of meeting the design load. Due to the relatively wide steps in sizes of cooling equipment this would in some cases avoid serious oversizing.

Florida State Board of Education Regulations Chapter 6A-2 does not specify a load calculation method. DGS Florida Energy Conservation Manual recommends and ASHRAE 90-75 requires use of the methods given in the 1972 ASHRAE Handbook of Fundamentals. This should be specified in Chapter 6A-2.

3. Relative Humidity

Refer to 4.2.7 and 5.4.2 of ASHRAE Standard 90-75

Humidity control can provide various benefits, including increased comfort under extreme conditions which might occur without such control. Extensive research indicates, however, that with sedentary people seated and working at desks the humidity can be varied over a wide range, from as low as 10 percent RH to as high as 80% RH with little or no change in the comfort sensation of the occupants of a space. In spaces where people are active, such as gymnasiums, high humidity does have an adverse effect on human comfort.

Humidity control may be desired for purposes other than human comfort. To prevent growth of mildew and molds relative humidity must be kept below 70%, and to prevent corrosion on exposed iron or steel relative humidity must be kept below 50%. Libraries require a relative humidity of 45-50% for best preservation of books, and temperature

below $72^{\circ}F$ to prevent propogation of bookworms; moreover, rapid changes in humidity and temperature should be avoided as this causes more rapid deterioration. Humidity level affects the survival rate of certain viruses and bacteria, however until more is known concerning this it should not be a factor in determining humidity levels for schools. Relative humidity is also an important consideration in odor control; high RH tends to reduce olfactory sensitivity. Again, until more is known concerning this it should not be a consideration in selecting allowable humidity levels.

Any type of humidity control will add to the first cost of a system and to the maintenance and operating costs from there on, therefore such control should not be employed unless required for some purpose other than to prevent minor discomfort. The DGS Florida Energy Conservation Manual states "Humidity control shall not be used except in special applications". ASHRAE Standard 90-75 provides for buildings in general that no energy will be used to add moisture to the air at levels above 20 percent RH, or to remove moisture from the air at levels below 65 percent RH. The Florida climate is such that in air-conditioned schools this requirement will generally be met without special humidity control equipment.

In the reviewer's opinion the portion of Chapter 6A-2.63 par b(6) which deals with humidity control is not well stated. It is suggested that changing the words "at not less than sixty (60) percent, plus or minus five (5) percent, relative humidity..." to "at not more than sixty-five (65) percent relative humidity..." is

desirable (Refer III, Recommended Revisions to Chapter 6A-2). There appears to be no purpose in specifying a lower limit for relative humidity; in fact a level of 45 to 50 percent would be desirable where this occurs naturally without added energy. For special spaces such as libraries and gymnasiums an allowable maximum RH of 50 percent appears desirable when these spaces are air-conditioned.

4. Operable Windows

Refer 4.5.3.1, ASHRAE Standard 90-75

There is little in the literature concerning this matter. One statement in NSF-RA-N-74-117 "Low Energy Utilization School" (ref. 4f) is pertinent. It states "By having operable windows, the amount of electricity used to operate fans and air-conditioning can be reduced by 30 percent. This constitutes a saving of 290 kwh/msf/yr." This study was conducted for the New York City area, and may not be applicable to Florida.

There are many considerations which will affect the decision as to whether windows should be operable. During spring and fall, and much of the winter here in Florida outside air is in an acceptable comfort range and can be used without treatment. To use this effectively, windows must be suitably located, and arranged in a manner to permit ventilation without objectional drafts. Also, operable windows permit use of the building when the heating or cooling system is "down".

Objections to operable windows are that they require manual control which is often neglected, that they may provide additional

opportunity for vandalism, and that they will require additional maintenance.

It appears that this is a matter which should be left to the discretion of local school boards and the architect-engineer, with the general recommendation that at least a portion of the windows in any space be made operable to provide an opportunity for natural ventilation when this would be advantageous from the standpoint of comfort or energy saving.

5. <u>Ventilation Rates in Heated Spaces</u>

Refer 5.3.2.3, ASHRAE Standard 90-75

In tests conducted by the National Bureau of Standards and by Dr. Ralph G. Nevins (ref. 4f) in actual classrooms the following ventilation rates were found to be sufficient and safe:

1. General ventilation for most activities 5 cfm/occupant
2. Ventilation in areas of intense physical activity 15 cfm/occupant

This is in agreement with the requirements of ASHRAE Standard 90-75.

The DGS Florida Energy Conservation Manual states that ventilation rates should be limited to 4 CFM per person, and that if more is required due to special conditions then charcoal filters should be investigated. It further recommends a 0.3 air exchange rate for corridors.

A reduction from 5 cfm/occupant to 4 cfm/occupant is not recommended, as this is not in line with generally accepted standards. The

overall saving from such a change would be minor.

NOTE: A further discussion of this subject may be found in NSF-RA-N-74-117 Lower Energy Utilization School - Research phase I, Interim Report - Sec. 6-2, (ref. 5f).

6. Variable Volume Systems and Ventilation

Refer to 5.8, ASHRAE Standard 90-75

Variable volume systems are acceptable from a ventilation standpoint, provided they are designed and controlled so as to meet minimum ventilation air requirements at all times, and to provide sufficient air movement to maintain comfort conditions. At no time should it be possible to reduce delivery below 50% of the design delivery.

A further discussion of this type of system is included under 13., Systems Selection.

7. Heat Recovery Systems

Refer to 5.9, ASRAE Standard 90-75

Any type of heat recovery system which will pay for itself in a reasonable length of time and which will provide an overall savings in energy should be encouraged. Condenser heat can be used for domestic hot water heating, for reheat, to supplement heat from solar or other sources, and for many other purposes.

Heat recovery by means of economisers would be restricted to rather large systems, but should be used wherever there is economic

justification for it.

As with economisers, heat recovery from incinerators should be used where economically justified. Rather than have an incinerator at all, a better plan might be to turn all waste over to a municipal or area waste collection system. Many areas have now constructed plants which use waste materials to produce steam in power plants, manufacture gas, extract various chemical products, etc. Such a plan would not only relieve school officials of the problems of operating an incinerator, it would provide a use for the waste materials collected.

Exhaust air heat recovery should be used to the extent justified, considering first cost for the equipment and maintenance and operating costs.

Other sources of heat recovery to be considered are heat from lights and equipment, heat from gasoline or diesel driven generators or compressors, and heat from kitchen exhaust systems.

In most cases the question of whether or not heat recovery is justified will depend upon the size, complexity, and location of the school, and the types of systems used. The Architect-Engineer should therefore be given wide latitude, with a general requirement that heat recovery systems be employed where they will save energy, and pay for the added investment cost.

8. Energy Efficiency Ratio (EER)

Refer to Tables 6.2, 6.4 and 6.5, ASHRAE Standard 90-75

An EER should be required on equipment and in many cases a

minimum EER should be specified. This information is now generally available from manufacturers.

9. Heat Pumps

Refer to 6.7 and Tables 6.7, 6.8 ASHRAE Standard 90-75

The use of heat pumps should be neither encouraged or discouraged. They should be considered along with other alternatives, and selected where they are found to be best suited for the application. After a long period of unfortunate experience with heat pumps, they have at last been developed to the point where they are reliable, and may prove to be the most economical source of heat. Heat pumps are now being used in conjunction with solar heating. ASHRAE Standard 90-75, and the DGS Florida Energy Conservation Manual, give some guidance on performance requirements for heat pumps. These should be adopted as minimum performance standards.

Additional Discussions/Recommendations based on questions raised by staff of the Educational Facilities Construction office.

10. Air Change Rates

The air change rate, or air loading to a space serves two general purposes; first, to provide sufficient air movement in the occupied portion of the space to promote good comfort conditions, and second, to provide uniform temperatures throughout the occupied portion of the space. The "occupied portion" is usually considered that space

between the 3" and the 72" level, and two feet or more from walls and partitions. Air movement from 20 fpm to 50 fpm is recommended. Movement of less than 20 fpm will cause a feeling of stagnation, while more than 50 fpm will cause a sensation of draftiness.

Air change rate can be expressed either as cfm per square foot of floor area, or as air changes per hour. The amount of air required to be supplied to a space to maintain a given design temperature is a function of the sensible heating or cooling load and the temperature difference between the indoor design temperature and the supply air temperature. In order to maintain a constant air change rate the temperature difference must be adjusted as the load changes.

Academic Building Systems (ABS) information manual 3 dated December, 1971 (ref. 13a) suggests the following minimum total air circulation rates:

a.	Offices	1 cfm/sq.ft.	6.7 air changes/hr.
b.	Classrooms	1½ cfm/sq.ft.	10.0 air changes/hr.
c.	Laboratories	2 cfm/sq.ft.	13.3 air changes/hr.
d.	Corridors	½ cfm/sq.ft.	3.3 air changes/hr.
e.	Toilets & Janitor Closets	2 cfm/sq.ft.	

It is further stated that the maximum air circulation rate should not exceed 3 cfm/sq.ft. in any single room, nor an average of 1.75 cfm/sq. ft. in the building.

In an article by Mr. Harold E. Straub, PE, Chief Engineer for the Titus Manufacturing Corporation, which appeared in the April, 1969 issue of <u>Heating, Piping and Air Conditioning</u> magazine, he says,

"the only general statement that can be made regarding room air motion and number of air changes is that 8 to 10 air changes per hour are required to prevent formation of stagnant regions."

It should be noted that the air change rate does not have to be provided by the air distribution or ventilation system, but can be provided by local air circulation fans. NSF-RA-N-74-117 Research Interim Report (ref. 4f) states "Ventilation through open windows can produce air change rates of 10 to 30 per hour."

Rather than specify an air change rate, it seems reasonable to specify air movement of between 20 fpm and 50 fpm in the occupied portion of all occupied spaces. The air change rate can be used as a rough check to see whether this requirement is met.

11. Air Distribution

For best comfort, air should contact the occupant from in front of and above at velocities between 20 fpm and 50 fpm. Air striking the occupant on the back of the head or neck, or around the ankles should be avoided. There is a wide selection of ways the air can be delivered, however, the mixing of supply air with room air should for the most part take place outside of the occupied zone. In classrooms, air is frequently delivered by unit ventilators located along the outside walls. This method is very satisfactory where noise from fans or excess air velocity is properly controlled, and yet velocity is sufficient to provide acceptable air movement throughout the space.

Mr. John R. Whitehouse, Manager of Field Engineering for Tuttle

and Bailey Division of Allied Thermal Corp., in a talk given at the University of Florida Air-Conditioning Conference in 1969 (ref. 11c), gave these general criteria for supply air outlets:

(a) For high air loading, i.e. 15 to 25 air changes per hour or 2.5 to 4.0 cfm/sq.ft., ceiling outlets with 360° delivery should be used. The term "air loading" is used to express the air change rate in terms of cfm per sq. ft. of floor area.

(b) For medium air loading, 10 to 15 air changes per hour or 1.5 to 2.5 cfm/sq.ft., multiple outlets or slots high on the wall or in the ceiling along the wall and delivering air toward the outside wall should be used.

(c) For low air loading, 5 to 10 air changes per hour or .75 to 1.5 cfm/sq.ft., individual high wall outlets delivering air in a spread pattern toward the outside wall is recommended.

The location of return or exhaust grilles has little effect on overall air movement in a space. Air movement and mixing is accomplished principally by the velocity and pattern of the supply air.

The above discussion is provided as a guide to satisfactory air distribution methods. The basic requirement is that the air be distributed in such a manner that it will not cause drafts, and will at the same time prevent areas of stagnant air.

12. <u>Cfm Requirements for Non-Air Conditioned Spaces</u>

There appears to be nothing in the literature to support the present 100 cfm requirement. It is far above the level needed for

metabolic processes or odor control, and appears to be above the level which would be beneficial for temperature and humidity control.

The outside air can be used for cooling only when its temperature is below that of the occupied space. A very simple equation $q = \frac{H}{1.08 \times \Delta t}$ gives the air flow required to provide a given amount of cooling. Take as an example a classroom with 30 students, 900 sq. ft. of floor area and 10 ft. high. Assume a $10^{\circ}F$ temperature difference and lighting at 2 watts per sq. ft. Since the outside temperature is below that of the space, heat loss would occur through the outside wall, and either a heat gain or heat loss would occur through ceiling and roof depending on whether sun was on the roof. Assume these two balance each other. The sensible space load is then approximately...

people	30 x 300 =	9000 Btuh
lights	2 x 900 x 3.4 =	6120 Btuh
	Total	15120 Btuh

The amount of air required to maintain the desired space temperature is $q = \frac{15,120}{1.08 \times 10} = 1400$ cfm.

Since 300 cfm is being supplied under the mandatory requirement the space will be at a temperature about 5° below the desired level. For lecture rooms, dining rooms, etc.,this difference would be even more extreme. Reduction in the outdoor air quantity should be permitted to the level required for ventilation purposes, with recirculation provided to insure proper air movement.

When the outside air temperature is above the desired indoor air temperature, it is obvious that introduction of outdoor air can only

result in the temperature of the air which is introduced being increased due to pick-up of the space cooling load. This will, however, result in a lower space temperature than would occur if no outside air were brought in. The resulting temperature would be a function of the space sensible cooling load, and the amount of outside air supplied. It would appear off-hand that the more air introduced the better, however, above a certain level the improvement becomes minimal.

In research conducted in connection with the Fallout Shelter Program (ref. 12c) it was found that with an outside temperature of 90° F to 95°F, an increase of air supply rate from 40 cfm/occupant to 60 cfm/occupant produced no measurable change in indoor conditions, remaining at about 1° ET (effective temperature) above the outdoor condition. No figures were shown for above the 60 cfm/occupant rate. While these results are not directly comparable to other types of structures, they indicate that rates above 60 cfm per occupant for cooling in fairly densely occupied spaces are of questionable value.

This appears to be an area where the provisions of par 6A-2.25 could be taken advantage of and some experimentation performed. The difference between 60 cfm/occupant and 100 cfm/occupant could make a significant difference in equipment first cost, as well as energy requirement and operating cost, and in noise level.

The matter of humidity level has not been discussed, however, that can be approached in a manner similar to that for temperature. Recently developed enthalpy controls could be tried in conjunction with the research suggested above.

Based on present information, corridors and halls should not have the same requirement for outdoor air. There should be some provision for circulation of air through these spaces. Population density in these spaces is usually low except for limited time periods. When high density for prolonged periods can be anticipated, the same provision should be made for them as for other densely occupied spaces. The ASHRAE "Handbook of Fundamentals" lists a ventilation requirement of 0.25 cfm/sq. ft. for corridors. The DGS Florida Energy Conservation Manual recommends 0.3 air changes per hour as the maximum to be permitted for such spaces.

13. Systems Selection

The architect-engineer should be given wide latitude in the selection of an air-conditioning system, provided it meets all of the requirements of the code and can be justified on a life-cycle cost basis. This last requirement would seem to preclude high pressure, high velocity systems, which are expensive both in first cost and in operating cost. Systems should also meet reasonable noise criteria requirements, which in my opinion are not sufficiently spelled out in the code.

A study and survey of school air-conditioning systems was made by Mr. Samuel P. Goethe, Consulting Engineer, in 1964 and the results reported in the Proceedings of the 13th Annual Air-Conditioning Conference at the University of Florida (ref. 13h). Mr. Goethe designed many of the systems now in use in Florida schools. His survey

included opinions of 150 practicing engineers on such items as temperature and humidity control, air cleaning, odor dilution, air motion, noise, and germicidal treatment, together with his own opinion of relative first cost, maintenance cost and operating cost. A copy of his report, together with a later study of air-conditioning systems in general made five years later, is included under separate cover. Goethe expresses a low opinion of variable volume systems, however, another consulting engineer, Mr. Edgar C. Jones, has stated that his firm has designed the variable volume system for a number of schools in the southeast, and they have performed well.

ABS Informational Manual 2 contains this statement, "Operational and maintenance costs exceed first cost by several times over during the lifetime of a building. They can vary from $1.25 OGSF (outside gross square feet) to $6.00 OGSF per year." This statement was made in 1971. These costs are much higher now, and will be even higher in the future. They should receive major consideration in the selection of a system.

The best basis for selection of a system would be a body of carefully kept maintenance and operational cost data on a large number of systems for an extended period of time. Along with this there should be periodic surveys to determine how well each system is performing its function. Unfortunately there appears to be no such body of information currently available. It is suggested that a statewide cost accounting and reporting procedure for mechanical systems be established, and this data used as a basis for determining which

types of systems are performing best and most economically (Refer VI, Recommendations for Further Study).

14. Central Systems

While central systems in most cases provide certain advantages, they should not be universally required. The system should be selected on a basis of its performance capabilities and its life cycle cost. This does not of necessity rule out incremental systems or packaged rooftop systems. These both offer advantages in certain situations, and the architect or mechanical engineer should be permitted to use them where the advantages can be clearly demonstrated. Noise level or any other inherent disadvantage must of course be taken into consideration. The versatility of these systems, such as permitting the use of one or two spaces at night or on weekends without operating a large plant is one of their specific advantages.

15. Remote Location of Equipment

A definition for the term "remote" must be established before discussing this subject. If "remote" means placed in a separate building, then it depends upon the size and type equipment referred to. Where the equipment presents a hazard when located within a school building, or where it presents noise and vibration problems such as with large reciprocating compressors or diesel driven equipment it should certainly be remotely located. Large cooling towers or evaporative condensers often cause noise and vibration problems,

and in some cases water spray problems, and in such cases should be remotely located.

16. Optimum Temperature for Learning Achievement

Considerable experimentation has been done in this area, however, unfortunately not enough to provide a firm answer. Perhaps the most extensive research was performed here in Florida in the Pinellas County Experiment conducted by Dr. Fred Stuart from 1961 to 1963 (ref. 16g). Here learning achievement, along with several other parameters, was compared between students in a completely air-conditioned junior high school and students in three non-air-conditioned junior high schools. While there was a slight indication of high learning achievement in the air-conditioned school, this was not supported by statistical analysis at a one percent confidence level. Several years later Drs. Nevins and McNall of the Institute of Environmental Research, KSU, made a much more complete study of the data which pinpointed some slight advantage for the air-conditioned school in some areas of learning, but no significant advantage (ref. 16j).

Research conducted at Kansas State University's Institute of Environmental Research in the mid-sixties by Drs. Pepler and Werner on "Temperature and Learning" (ref. 16m) indicate that the optimum temperature for learning achievement is slightly higher than that for the optimum comfort. Best learning achievement was found to occur at $80^{\circ}F$, however, there was no significant difference over a range from $68^{\circ}F$ to $86^{\circ}F$. Learning rate was better at temperatures above $86^{\circ}F$

than at temperatures below $68^{\circ}F$.

Much more research is required to establish an optimum temperature for best learning achievement. This no doubt is dependent to some extent on local climate conditions, habits in dress, and other variables. With present knowledge it appears best to provide a climate at or slightly above the optimum comfort level.

17. Efficiency of System Components

This appears to be too broad a subject to be properly covered here. It encompasses such items as boilers, furnaces, fans, compressors, coils, condensers, evaporators, controls, pumps, duct systems, piping systems, etc. The engineer should consider efficiency of the components of the system he designs, along with their dependability, durability, and cost. Information upon which to base a selection must come from manufacturers' literature, information from independent test laboratories, and his own experienced judgment. Life cycle cost rather than first cost should usually be the criteria governing final selection.

18. Multiple Energy Sources

It is desirable to have energy available from multiple sources, though not critical in the sense it is critical for power plants or hospitals. For larger installations, interruptable gas to fire boilers with oil as a back-up might be desirable. Electrical tie-ins to feeder lines from different directions could prevent shut-down in

case of failure in a sub-station. Solar used for space heating will, considering the present state of the art, require full capacity back-up from other sources. The use of electric for space heating as a back-up for fossil fuels is not recommended except for special cases.

19. Types of Condensers

Proper condenser selection will in most cases be governed by local considerations. The architect-engineer for the particular project should be best suited to make this selection.

Some general guidelines can be given. There are three types of condensers in general use; shell and tube, evaporative, and air cooled. Shell and tube condensers are generally used on large installations, and may be supplied with cooling water from wells, from lakes or streams, or from cooling towers or spray ponds. Where good quality water is available from wells and there is no possibility of excessive draw-down or thermal pollution this may be the best selection.

When water conservation is essential, a cooling tower or spray pond may be the best solution. This will add to the first cost and maintenance cost, but will result in the loss of only about 5% of the water circulated.

An evaporative condenser will generally be less expensive than a shell and tube condenser with a cooling tower and will require less space, however, it may cause noise problems. Water requirement will be about the same for either.

Air cooled condensers, once thought to be inefficient and unsuited for large installation, are now used in sizes up to 500 tons. Power and maintenance requirements are low, however, power requirement to the compressor may be higher due to higher head required during hot weather. They may be placed on roof-tops. The noise level, if the unit is properly installed, is low when compared with a cooling tower or evaporative condenser.

20. Cfm Requirements for Industrial Spaces

The amount of air to be supplied to an industrial space would depend upon the nature of the work performed in the space, and the exhaust air requirement of the space. The Industrial Ventilation Manual of the American Conference of Governmental Industrial Hygienists (ref. 20k) should be used as a guide both as to exhaust air requirement and as to the method of exhausting the air. This manual also establishes allowable levels of the various toxic gases or vapors which may be generated, and the dilution rate required to maintain these levels. The manual should be listed as a required standard under par 6A-2.45. In general no return air from industrial spaces should be circulated to other portions of the building. A slight negative pressure should be maintained to prevent exfiltration to other spaces.

Other mandatory reference codes should be NFPA 91: Blower and Exhaust Systems, and NFPA 96, Commercial Cooking Equipment, Vapor Removal.

PART II - ENERGY CONSERVATION

It is recommended that a modified version of Appendix B, "Summary of Energy Conservation Opportunities", a part of Energy Conservation Guidelines for Existing Office Buildings, be used as interim guidelines for energy conservation. This document was prepared by the Public Building Service of the G.S.A., published in 1975.

As the name implies, the material provides guidelines for "... modifying, adapting, renovating, operating and maintaining existing office buildings to achieve greater energy efficiency than presently exists." The following is an outline of the 53-page appendix as it appears in the Table of Contents.

A. General
B. Site
C. Building
D. Lighting
E. Power
F. HVAC
G. Plumbing
H. Vertical Transportation
I. Solid Waste
J. Operation and Maintenance

It should be noted that these guidelines are in no way mandates and are developed in check list form as suggestions or considerations. There are a number of other publications with similar listings, however this particular document is recommended for a number of reasons. First, it appears to be almost a compilation of many of the lists found in earlier publications, and as such is more comprehensive in scope. It also establishes a key based on representative climate features and suggests a priority system for evaluating potential energy savings.

There are a number of limitations to the guidelines that must be addressed before it becomes a useful document for the Office of Educational Facilities Construction. The guidelines were written for office buildings and a number of items (E.g. Vertical Transportation) are not always pertinent to school construction. There is also a heavy emphasis on heating as opposed to cooling, a concern that tends to be reversed in Florida. Finally, because of the broad base of the study, the suggestions tend to range from the obvious (turn off the lights at night) to suggestions that imply expensive and time consuming studies (E.G. "Compare original design assumptions against building actuality").

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ANALYSES AND RECOMMENDATIONS

RELATED TO PUBLIC SCHOOL CONSTRUCTION

Section II - LIFE CYCLE COSTING FOR EDUCATIONAL FACILITIES

LIFE-CYCLE COSTING FOR EDUCATIONAL FACILITIES

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LIFE-CYCLE COSTING FOR EDUCATIONAL FACILITIES

Part I - Building Cost

Introduction

In his book, Building Economics, Ivor B. Seeley presents a very brief but concise history of the concept of determining the cost of buildings.

"Cost planning, as it presently operates, is the logical extension of a process which has continued since the days of the eighteenth-century measurers, who were employed to measure and value the cost of work after it was both designed and executed. Thus the measurers were involved after the building was erected, to measure and value and to argue with the client and architect on behalf of groups of tradesmen, who at that time had not been brought together under a main contractor. The main contractor system, which became fully operative in the early nineteenth century, implied price competition before construction which previously was a rare happening. The measurers soon realized that a new function was required and that they possessed the necessary skills to undertake it. It was in response to this situation that they developed the skills of pre-measuring, of taking off quantities from the drawings before construction started and assembling them in a bill of quantities to provide a rational basis for competition. At that time it constituted an extremely valuable contribution of the building process. Hence, the work was measured and priced before execution, but after design.

The next development was the introduction of approximate estimating techniques which attempted to give a forecast of the probable cost, although the basis of the computation often left much to be desired. It was subsequently realized that by the use of cost planning techniques and the methods of cost analysis on which they depend, probable cost can be reasonably accurately determined early in the design process, and sometimes even before the design is commenced, and can be identified with the clients' own required limit of cost."

We have reached another milestone in the evolution of building cost design. Not only are we interested in what the building will initially cost but what it will cost to keep it functional in the years ahead. This idea of trying to determine all the costs associated with a building from the time it is conceived until it is

demolished is termed the life-cycle-cost of a building. In addition the methodology of life-cycle costing has opened the door for comparing construction alternatives in a manner never before possible.

Cost Comparisons: The Need

There is little doubt that eventually life-cycle costing would have become an important tool for architects in making design decisions, but the energy crisis with its specter of steadily rising fuel costs has brought the idea to the immediate forefront in hopes that it would be a panacea to weary owners and irate taxpayers who are suddenly concerned with reducing the long-term overall cost of a building.

There are good reasons to be optimistic about the potential of life-cycle costing. Take for example the Fairfax County (Va.) Board of Education rejecting the low first-cost bid for a $1-million HVAC system for Chantilly High School and awarding the contract for an alternative HVAC system which costs 10% more but promised lower life-cycle cost. The winning HVAC system was figured to save the school board $282,000 over its 20-year useful life. This savings would become even more spectacular, about $600,000, if energy costs continue rising at 8% annually. With the large savings that can be achieved from life cycle reductions, the question is not whether to, but how to, use life-cycle cost analysis.

Building Cost Breakdown

What exactly constitutes the cost of a building over its entire life? Normally there are three general categories:

(1) initial cost (also called capital cost)

(2) operating and maintenance cost.

(3) renewal cost.

Category (1) includes all the front-end project costs - everything from land and construction cost to architectural engineering and legal fees. Category (2) can include, in addition to annual operating and maintenance costs, such items as real estate taxes and insurance. Category (3) includes replacement costs of components having shorter life spans then the life of the building.

The current system of awarding contracts on the basis of first cost only is destined to become an ever bigger folly as the energy crisis intensifies and fuel costs rise. In these days of rapidly escalating building costs, which were up 70% nationally between 1966 and 1972, the impulse to cut initial cost becomes almost reflexive. Yet over a building's lifetime, what appears as initial savings almost always prove expensive in the long run.

A school should be conceived not merely as a physical structure, but as a building for people designed to last at least 40 years. Viewed in this light, if a building is used for 40 years the teaching-administrative cost represents 80% of the total 40-year cost. Operating and maintenance cost represents 12%, and initial construction cost which usually dominates the economic picture fades into the background at 8% as shown in Figure 1 . This means that even when the initial

construction cost of the building is increased 10% it only increases the total life-cycle cost by 1%. Hopefully this 10% increase will result in lowering the total life-cycle operating and maintenance cost by more than 1% and thus create a net savings in the life of the building.

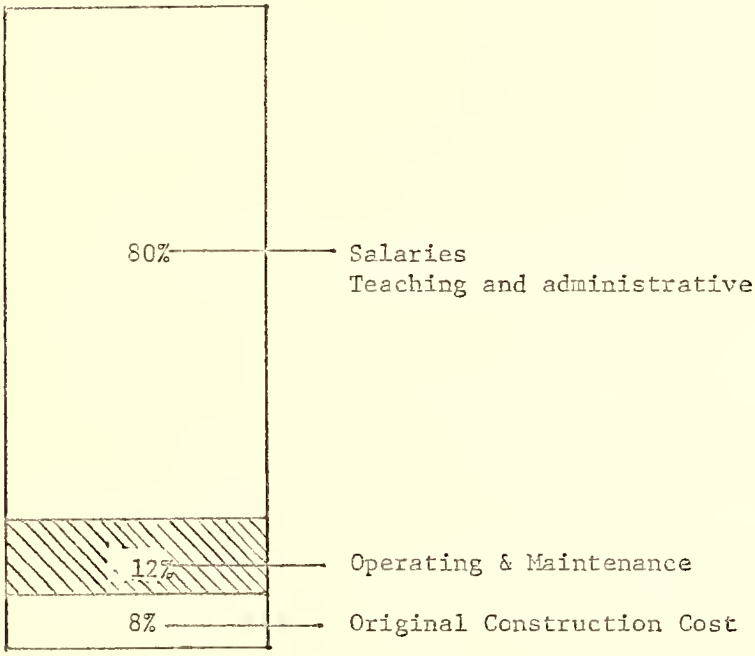

FIGURE 1: TOTAL 40-YEAR COST OF A SCHOOL

Source: The Economy of Energy Conservation in Educational Facilities, Educational Facilities Laboratories, 1973

Over a life of 60 years the initial cost of the building will be only about 6% of the total cost of fulfilling the purposes for which the building was built in the first place. Or to put it another way, when two teachers are added to a teaching staff, their salaries and fringe benefits for 30 years would equal the cost of $1 million worth of building.

It is important to describe the initial building cost accurately. In addition to the completed structure there are site work, equipment, furnishings, architects' fees, legal fees, blueprinting, site surveying and other miscellaneous items. From Figure 2 we see that the actual building cost will be about 74% of the total initial project cost.

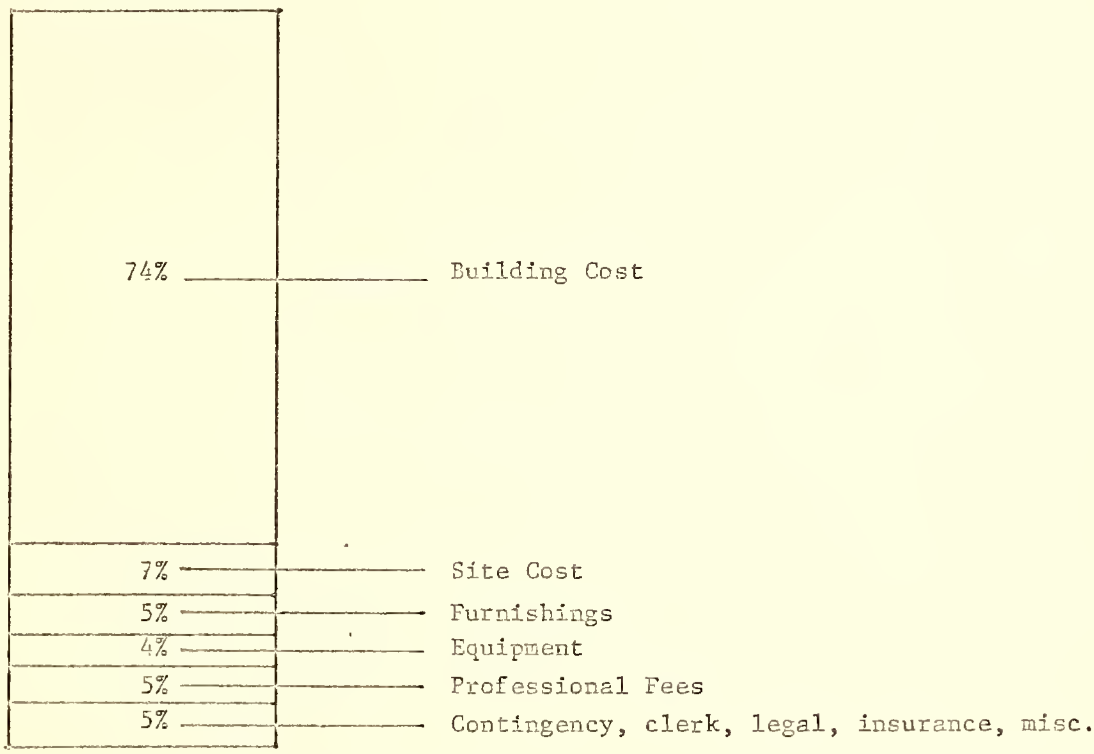

FIGURE 2: TOTAL COST TO CONSTRUCT A SCHOOL

Source: "The Price of the Schoolhouse", by Earl R. Flansburgh, Progressive Architecture, Feb. 1972

Looking at a breakdown of just the 74% which represents only the building cost, it is easy to quickly locate the major areas of initial cost, as shown in Figure 3.

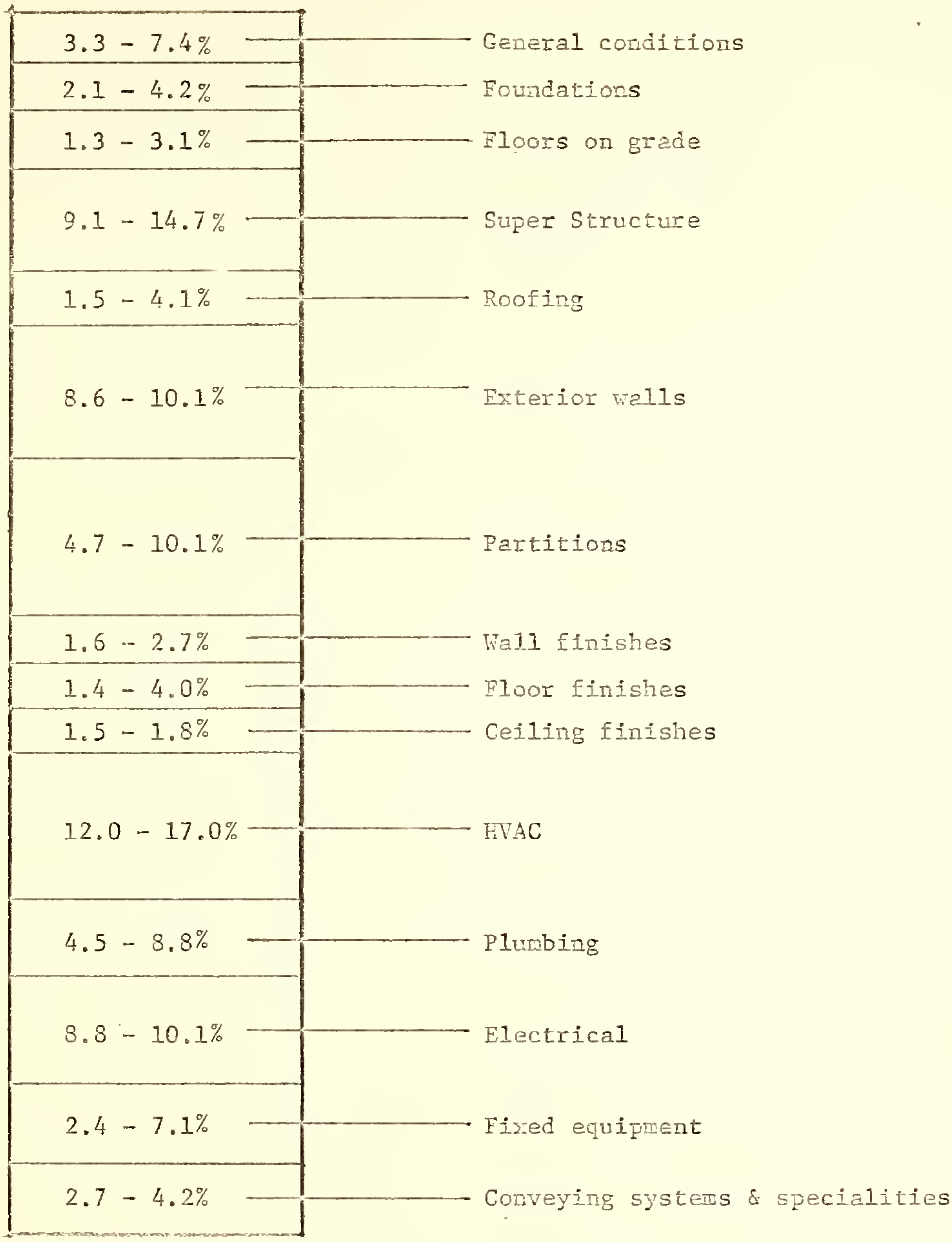

FIGURE 3: MAJOR AREAS OF SCHOOL BUILDING COST

Source: Based on Survey of 8 School Buildings Across the Country

Although the building cost represents 74% of total initial project cost, major efforts to control costs must center around the most substantial items. Effecting a 50% savings in an item that represents only 1% of the cost has little influence on the total building costs. This saving becomes even less significant when viewed in the perspective of a life-cycle cost for 40 years as seen in Figure 4.

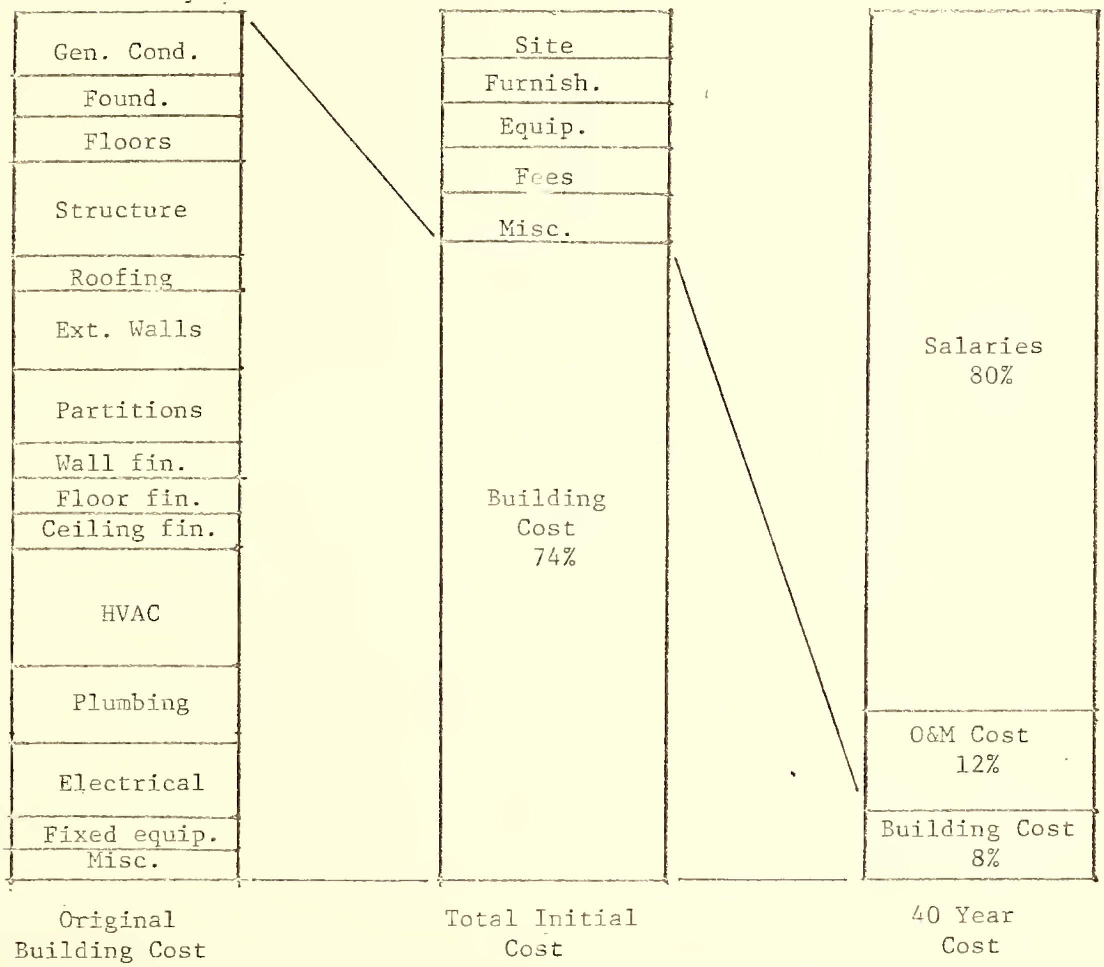

FIGURE 4: SIGNIFICANCE OF ORIGINAL BUILDING COST OVER 40 YEAR LIFE OF BUILDING

Source: Bureau of Research, College of Architecture, University of Florida, 1976

In fact an item must represent at least 17% of the building cost to have even a 1% influence on the 40 year cost of the building.

Of course some initial items such as heating and air-conditioning systems not only affect building costs but also affect operating and maintenance cost and thus may increase or decrease the total 40 year operating and maintenance figures. However, some construction experts raise major objections to using life-cycle costing in regard to operating and maintenance cost. They believe the uncertainty of performance of some equipment means that the operating and maintenance costs are estimated while the initial cost is clearly defined. Economists are quick to point out the fatal flaw in this argument, which is that while the initial cost is certain, the equipment's life span is not. Thus the initial cost of ownership will vary depending on the life span of the equipment. Initial cost entails uncertain assumptions on estimated useful life spans. Two identically priced building components carry the same initial cost only if they have the same useful life span. Without a specific life span, a simple price comparison is meaningless. Take for example HVAC systems A & B

	A	B
Initial Cost	$500,000	$1,000,000
Life Span	5 years	20 years

When these systems are compared using life-cycle costing at an interest rate of 6%, the initial cost of System A will be about 36% more than System B. *To equate initial cost with total owning costs is never justifiable.*

Part II - Life-Cycle Cost Analysis

For an accurate comparison of alternatives, cost must be reduced to a common basis. For most building where the owner pays initial or capital cost as well as operating and maintenance costs, there are two basic techniques for the computing of life-cycle cost.

1. Benefit-cost analysis
2. Comparison of long-term owning cost

The first method, benefit-cost analysis, formalizes the decision confronting an owner who must decide whether an initial improvement is economically justified. Virtually every decision that is made entails to some extent a form of benefit-cost analysis. We are constantly balancing costs in terms of time, money, or effort against benefits such as saved time or simply satisfaction. In benefit-cost analysis all costs and all benefits must be reduced to a monetary value and the ratio computed. If the benefits exceed the costs, then the project is economically justified. The common practice is to determine exactly how economical the project will be in terms of a percentage rate. This percentage is compared against the percentage rate of other projects and the one showing the highest percentage is the most economical.

The second method, direct comparison of long-term owning cost, based on life cycle cost, reduces all costs of each item or system to a single dollar value. The items can then be compared on an equal basis. There are two primary methods of reducing cost to a single value. One method is referred to as the "annual cost method" and the other is referred to as the "present worth method." Each of these

methods is explained in more detail in the following sections.

In the simplest use of comparing alternative systems with equal useful lives, the lowest total cost amount is easily determined.

	A	B	C
Initial Cost	\$10,000	\$15,000	\$20,000
Life Span	3 years	3 years	3 years

Since each system will last 3 years, the one with the lowest initial cost would be the most economical choice. But when the systems have different useful lives, and when the operating and maintenance costs are also included, the problem becomes more complicated.

	A	B	C
Initial Cost	\$10,000	\$15,000	\$20,000
Life Span	5 years	7 years	9 years
O & M	\$400/year	\$350/year	\$300/year

All of these costs must be equated on some equal basis and the total cost reduced to either a "uniform annual cost" or a "present worth cost" before a comparison can be made. After this has been done then the system with the lowest "annual cost" or lowest "present worth cost" becomes the most economical alternative.

The most common error in life-cycle costing involves attempts to compare <u>initial cost</u> with <u>annual cost</u> and neglect the interest rate of money. You cannot, for example, claim that an item which has an initial cost of \$100,000 and saves \$10,000/per year is paying itself

off in 10 years. At 6% interest, it takes slightly more than 15 years for the item to pay for itself. This comparison can be computed using standard interest tables.

\$100,000 @ 6% interest for 10 years	= \$179,100
\$10,000/year @ 6% interest for 10 years	= \$131,800
The payback amount is still short by	\$-47,400
\$100,000 @ 6% interest for 16 years	= \$254,000
\$10,000/year @ 6% interest for 16 years	= \$256,700
The payback has now exceeded the investment by	\$ 2,700

Life Cycle Costing - The Methodologies

Because of all the recent attention given to Life-Cycle Costing, it is very easy to assume that a new method of economic analysis has been invented. However, an engineer would quickly recognize it as basic engineering economy and an economist could easily identify the economic models on which it is based. This is because Life-Cycle Costing, as are most problems in economics trying to determine what is economical over a considerable time period, are bound by one common assumption; the time value of money. The idea of an interest rate causes the value of money to change with time. It is this idea - the growth of money over time - that must be taken into account in all combinations and comparisons of payments.

The process of taking into account the time value of money when making a dollar comparison requires the use of interest formulas. There are six basic formulas that can be used to build mathematical models which represent cost over a given time period. From these formulas economic models can be constructed to compare alternative systems.

The two most important types of models used to evaluate alternatives are the annual cost model and the present worth model. The simplest and easiest to understand is the annual cost model. In this model all cost and benefits for the life of each system are transformed and compared as a uniform yearly cost. The system with the lowest yearly cost would be the best selection. The second type of model transforms all cost and benefits for each system to a total present day value. These total present worth values are then compared and the alternative with the lowest value or cost is selected if other things are equal.

Life Cycle Cost Models

It is probably not possible to really understand Life-Cycle Costing without understanding how these two models work as well as how the interest formulas operate.

There are six basic formulas used in evaluating these costs. These formulas are symbolic representations of a system of known or assumed facts.

The following symbols and their definitions must be understood to apply the formulas in economic model building.

i = interest rate per period

y = the number of interest periods

P = the present worth or value today

F = the future worth of money or value at y interest periods in the future

A = a uniform end of period sum of money such as an annual payment at the end of the year.

In most of the economic models used to evaluate various alternative systems involving several years of service, the year is taken as the interest period y and the interest rate i is the interest rate per year. However, the interest period could be months, days, or continuous compounding could be used, but the relative difference between alternative studies, using more frequent interest periods with the appropriate interest rate, is so small that for practical application the annual rate and interest period is normally used.

Interest formulas are used to move values forward or back in time so that they may be compared on an equivalent basis with other systems of value. The 6 formulas which relate the variables interest (i), years (y), present worth (P), annual worth (A) and future worth (F) are shown below.

1. SINGLE COMPOUND AMOUNT FORMULA (SCA)

$$F = P(1+i)^y$$

used to find the future value, F, of a present sum of money, P, y years from now using an interest of i.

2. SINGLE PRESENT WORTH FORMULA (SPW)

$$P = F\left[\frac{1}{(1+i)^{y}}\right]$$

used to find the present worth, P, of a future sum of money, F, that is y years from now, using an interest of i.

3. UNIFORM COMPOUND AMOUNT FORMULA (UCA)

$$F = A\left[\frac{(1+i)^{y} - 1}{i}\right]$$

used to find the future worth, F, of a series of uniform annual end-of-year costs, A, in a given number of y years, with an interest rate of i.

4. UNIFORM SINKING FUND FORMULA (USF)

$$A = F\left[\frac{i}{(1+i)^{y} - 1}\right]$$

used to establish a uniform annual payment, A, that will produce a future sum of money, F, in given number of years, y, with an interest rate of i.

5. UNIFORM CAPITAL RECOVERY FORMULA (UCR)

$$A = P\left[\frac{i(1+i)^{y}}{(1+i)^{y} - 1}\right]$$

used to recover a present sum of money, P, in uniform annual increments, A, in a given number of years, y, with an interest, i.

6. UNIFORM PRESENT WORTH FORMULA (UPW)

$$P = A\left[\frac{(1+i)^{y} - 1}{i(1+i)^{y}}\right]$$

used to find the present worth, P, of uniform annual cost, A, in a given number of years, y, with an interest of i.

Looking at the above formulas reveals that in each one a single sum of money is multiplied by a certain factor. Each factor contains the unknown $(1+i)^y$ which is manipulated in different ways. It is obvious that for any one interest period (i) and for any number of years (y) the unknown is constant and thus makes the whole factor constant. Consequently, a table of factors can be developed and thus eliminate the necessity of calculating the factor each time its use is required. These factors are given in Tables 1 through 12 for various interest periods y with interest 2%, 4%, 6%, 8%, 10%, 12%, 15%, 20%, 25%, 30%, 40%, and 50%. If the exact interest period or interest rate is not given in the Tables, an approximate value can be obtained by straight-line interpolation between tables or values in a table. The factors given in these Tables have been rounded off to four significant figures. Larger tables containing more interest periods and interest rates to five and six significant figures are available if greater accuracy is required. However, for most economic analysis of alternatives, it is satisfactory to use these Tables with straight-line interpolation. Should greater accuracy be required, the particular factor needed can also be calculated by using the interest formula.

At the top of each Interest Table the alphabetic symbol for the factors is given, and under each, the symbols involved with that factor are given. Each factor involves an interest rate i, an interest period y, and two of the three symbols, P, F, and A. The first symbol, at the top of the column, is the known, and the second is the unknown. If P is given and you wish to find F, you would use the SCA. If F is

known and you want to find P, SPW would be used.

When the interest formulas are used in life-cycle costing they are expressed as factors in economic models. For instance the model to find the present worth of \$1000 to be received 5 years from now at 6% interest would be set up as:

$$P = F(SPW;y;i)$$

or

$$P = 1000\ (SPW;5;6\%)$$

A person familiar with life-cycle costing models would know to go to the interest tables and find the SPW factor for 5 years at 6% interest and multiply it by \$1000.

$$P = 1000(.7473)$$

$$P = \$747.30$$

Each interest formula is modeled in life cycle costing and appears as the following:

1. SINGLE COMPOUND AMOUNT FACTOR (SCA)

   $$F = P(SCA;y;i)$$

2. SINGLE PRESENT WORTH FACTOR (SPW)

   $$P = F(SPW;y;i)$$

3. UNIFORM COMPOUND AMOUNT FACTOR (UCA)

   $$F = A(UCA;y;i)$$

4. UNIFORM SINKING FUND FACTOR (USF)

   $$A = F(USF;y;i)$$

5. UNIFORM CAPITAL RECOVERY FACTOR (UCR)

   $$A = P(UCR;y;i)$$

6. UNIFORM PRESENT WORTH FACTOR (UPW)

   $$P = A(UPW;y;i)$$

A simple example of life-cycle cost analysis on an annual cost basis and a present worth basis is shown below using the following forecasted cost and expected benefits for two subsystems. An arbitrary interest rate of 10% is chosen to represent the expected benefits of the most economical alternative

	System A	System B
Useful Life	5 years	5 years
First Cost	$25,000	$30,000
Operating & Maintenance Cost (O&M)	$ 6,000	$ 4,000

ANNUAL COST COMPARISON

A = First cost X (Uniform Capital Recovery Factor) + O&M cost/per year

A = P(UCR;y;i) + O&M/year

System A:

A = $25,000 (UCR;5;10%) + $6,000

A = $25,000 (.2638)* + $6,000

A = $6,595 + $6,000 ....= $12,595/year

System B:

A = P(UCR;y;i) + O&M/year

A = $30,000 (UCR;5;10%) + $4,000

A = $30,000 (.2638)* + $4,000

A = $7,914 + $4,000..................................= $11,914/year

Net difference life-cycle annual cost $12,595 - $11,914 = $ 681/year

In this case system B would be the most economical alternative.

* Taken from Table for 10% interest under UCR Column for 5 years.

PRESENT WORTH COMPARISON

P = First cost + O&M cost/year X (Uniform Present Worth Factor)

P = First cost + O&M cost/year (UPW;y;i)

System A:

P = \$25,000 + \$6,000 (UPW;5;10%)

P = \$25,000 + \$6,000 (3.791)

P = \$25,000 + \$22,746.................................... = \$47,746

System B:

P = First cost + O&M cost/year (UPW;5;10%)

P = \$30,000 + \$4,000 (UPW;5;10%)

P = \$30,000 + \$4,000 (3.791)

P = \$30,000 + \$14,464.................................... = \$44,464

Net difference in life-cycle present worth value
\$47,746 - \$44,464 = \$ 3,282

Again System B would be the most economical alternative. This must be true since either the annual cost model or present worth model must reflect the same relative difference between the alternatives.

From the above examples it should be apparent that as more data is included in the analysis the process becomes more complex and the chances for error become greater. This is especially true for present worth models when different life spans are used. In present worth models if the life spans are not equal they must be made equivalent. If for example the life span of one system is 4 years and the life span of another system is 5 years the models would have to be compared on an equivalent base of 20 years with renewals occuring every 4 years for one system and every 5 years on the other system. The annual cost model does not have this limitation and is thus easier to use.

Part III - Further Discussions on Life-Cycle Costing

From the previous section it can readily be seen that the mathematics of life-cycle costing are not difficult once the economic models have been established. Complete and accurate analyses are possible only after the fact, but estimates of future facts of a system can only be forecasted. The design process is an iterative one with the designer questioning each assumption, re-examining objectives and formulating new ones, developing new alternatives, and so on until time, creativity, or resources dictate a decision. Because of this design process it becomes imperative that all those involved with the building process understand more than just the mechanics of life-cycle costing. They should be aware of such things as:

1. When should life-cycle costing be implemented?
2. What items should be included in a life-cycle analysis?
3. Data - What is available and what is needed?
4. What interest rate should be used?
5. What are the effects of inflation?
6. What life span should be used?
7. Which method should be used?
8. Who should be involved in a life-cycle cost study?

1. When should life-cycle costing be implemented?

As illustrated in Figure 5, the potential for application of life cycle cost analysis exists at all decision levels. It also illustrates that the most important decisions and thus those which save the most money over the life of the building are made by the owner. The manner in which an owner states his design criteria and standards can have a great impact on how many alternatives will be available for an economical building.

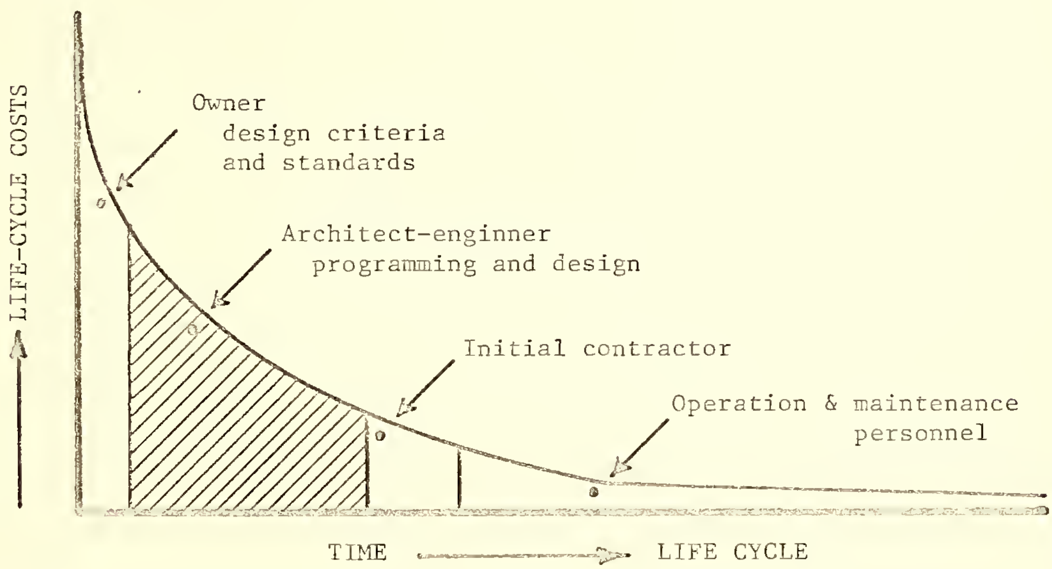

FIGURE 5: THE EFFECT OF DECISION TIMING ON LIFE CYCLE COST

Source: Report on the use of Life Cycle Cost Analysis in the Development of Health Facilities, Section IV, Department of Health, Education and Welfare.

For example if an owner specifies an HVAC system that must be total electric, he is entirely eliminating the investigation of gas systems to perform the same task. With this type of design criteria the architect or engineer can do life cycle cost comparisons on numerous

electrical systems and still not select the most economical system to do the job.

As a project proceeds it becomes increasingly difficult to change an earlier decision and the benefits of using life cycle costing begin to decrease as represented in figure 5. It is also pointed out in figure 6 that not only is the potential for savings from life cycle cost analysis greater the earlier it is implemented, the savings potential decreases as the program ages. A small expenditure for a life cycle cost study can have a large impact on potential returns only when it is implemented at the proper time.

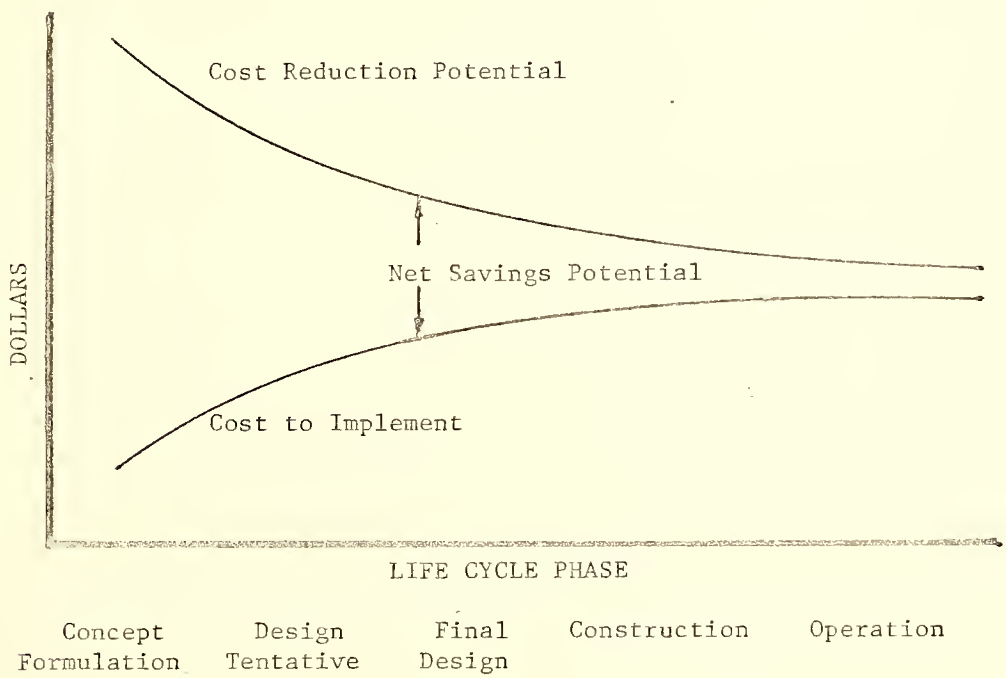

FIGURE 6: LIFE CYCLE PHASES AND SAVINGS POTENTIAL

Source: General Services Administration Handbook, Value Engineering, PBS P 8000.1, 1972

2. What items should be included in a life cycle analysis?

Theoretically every building component could be analyzed using life cycle costing but in many instances the savings would not justify the cost of the analysis. A few years ago an economist named Vilfredo Pareto developed the curve shown in figure 7 which became known as Pareto's law of distribution.

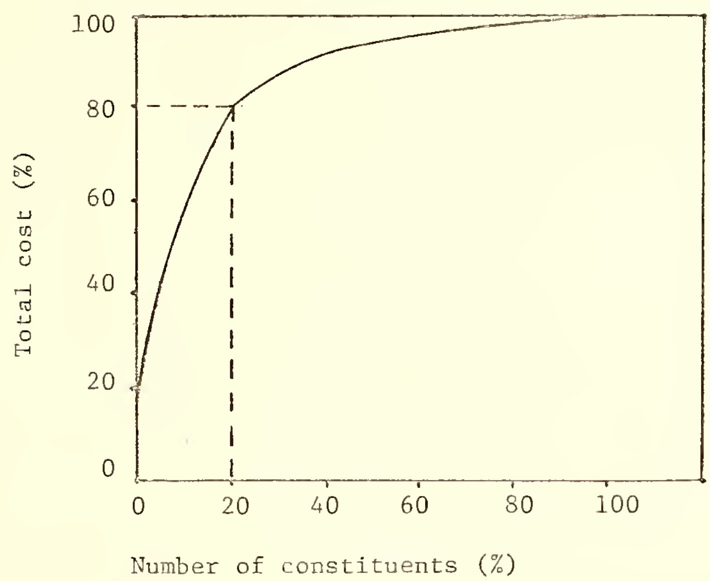

FIGURE 7: PARETO'S LAW OF DISTRIBUTION

Source: Value Engineering in the Construction Industry, by Alphonse J. Dell'isola, 1973

This curve has general applications to all areas where a significant number of elements are involved. It points out that in any area, a small number of elements, 20%, contain the greatest percentages of cost, 80%. Similarly a small number of elements will constitute the greatest potential for savings. Referring back to figure 3 it can be

seen that the average HVAC systems (14.5%) and the average electrical system (9.5%) would total over 20% (23.0%) of a school building cost.

3. Data - What is available and what is needed?

Reduced to its bare essentials, the concept of life-cycle costing applied to building requires data from three general categories:

(1) Initial or capital cost

(2) Operating and maintenance costs

(3) Renewal cost

As simple as this may seem, very little useful data exists in published form. Most life cycle analyses depend upon data specifically developed to reflect the unique aspects of the facility under study. Although some general data can be valuable as a starting point for many analyses, eventually a comprehensive data base must be utilized. A comprehensive data base not only significantly facilitates the analyses, but also opens up many more decision areas for analysis. A comprehensive data base is, however, a slow and potentially complicated system to develop.

Initial or capital cost is the area where most data collection efforts are currently taking place. It is also the area where historic cost data would be the most relevant. Capital cost would include such items as: site acquisition, design and engineering fees, construction, furniture and equipment, cost of relocation and interim financing. The efforts underway concentrate on collecting data on construction cost rather than full project costs. Of these two, the construction costs are the most difficult to accurately estimate. The recognition of local market conditions is almost exclusively intuitive and thus the process of arriving at an estimate is as much an "art as a science." This

factor, combined with the severe shortage of data for comparative preliminary studies of entire facilities and building systems, means that the problem of accurately estimating the first cost has yet to be completely resolved.

Operating and maintenance cost data is in about the same status as capital cost data. To date no meaningful historical data has been collected on most areas of operating cost because one owner may be maintaining a facility in mint condition while another may permit considerable deterioration. The national or regional information sources which do exist are only valuable in that they provide a reference datum against which building operators can measure current operation and maintenance cost levels. Accurate data concerning the life span and maintenance cost of various materials is virtually non existant. In order to make up for the lack of suitable data, the life-cycle cost analyst is forced to patch together information from a variety of sources such as component performance data, individual accounting records, etc. In some instances there is simply no data available and the analyst can rely only on intelligent guesswork. Questions of relating cost data to quality standards, building age, operating policies and schedules, regional differences further complicate the problem.

The following example depicts the importance of using accurate operating and maintenance data. In a study of two identical Connecticut schools with all-electric HVAC systems it was discovered that one school recorded nearly double the energy consumption of the other. A subsequent inspection revealed the major cause of this tremendous energy waste was the continuous inactivation of the outside damper control.

Vast quantities of needless cold air had to be heated to interior design temperatures. Dirty filters, another major failing in the operating and maintenance program, obstructed delivery of heated air at a great waste of electric power. The useless, day-long lighting of a cafetorium and other generally unoccupied spaces, plus unnecessarily high thermostatic settings, rounded out an operating and maintenance program unconsciously dedicated to maximizing waste. As a matter of interest is should be mentioned that "by general expert consensus, faulty operating and maintenance procedures waste tremendous quantities of energy."

Besides the major and essential cost data required for the initial building components and the operation and maintenance of the facility, renewal cost also affects the total life-cycle picture. Many of the individual elements which make up the building have a shorter life-cycle than that planned for the entire facility. As a result replacement costs sometimes become important cost items after the first few years of operation. Their most important role takes part in the evaluation and selection of major alternative systems and other limited building materials.

Here again published data on repair, alterations and replacement costs are practically non-existent. Even organizations responsible for the long term management of buildings, rarely record this type of cost information in any adequate form. There is often considerable confusion between accounting for renewal items, maintenance items and capital improvements.

4. What interest rate should be used?

At various examples in this discussion a particular interest rate has been stipulated without any explanation of why that particular interest rate was chosen. Although it is basically the idea of interest that makes money change over time, the primary concern is the "rate of return" of an investment.

The term "rate of return" is simply the percentage of money that will be returned over and above an original investment. If the money returned is more than the original amount invested a profit is realized. For instance if $1,000 is put in a savings account at 6% interest the rate of return after one year will be $60 ÷ $1,000 or 6%. If the money had been invested in stocks which increased in value by $100 the rate of return would have been $100 ÷ $1,000 = 10%. Figuring the rate of return on an investment is easy when all the facts are known. Predicting the rate of return on a future investment becomes more difficult. The rate becomes especially important when comparing two or more alternative systems having different costs. It is possible, in some cases, for a change in the rate of return to shift the relative positions of alternatives being subjected to life-cycle cost analysis.

Deciding on a minimum rate of return for an educational facility is difficult to establish, but if the analysis is a comparison of alternatives using this minimum attractive rate of return, it must be established. There are several ways of doing this. In private industry the management may as a policy give their cost center a rate of return to use. The Executive Office of Management and Budget for the U. S.

Government in the Directive A-94 dated March 27, 1972, states that 10% be used as the minimum attractive rate of return, if no other value has been established for a project.

The minimum attractive rate of return reflects the cost of using money and the risk that the project the money is used to finance may fail to produce the expected results. The cost of money includes the basic cost of money, which can be considered to be the highest interest rate the government pays for borrowed money. If money is not used on a project, the government could save the interest they would have to pay on the money they would not have to borrow. They would, of course, not borrow from the source that had the highest interest rate, thus establishing the basic cost of money. If the government ever reached the position of not operating on borrowed money, this basic cost of money would be the rate of interest they could obtain by loaning money to other sources.

Eventually the Federal Government system will be able to assign minimum attractive rates of return to its various cost centers based on similar risk considerations. Until that time all economic models should use a minimum attractive rate of return of at least 10%, and the state should establish different rates for projects within their control based on the risks involved and available money.

A state should recognize that every time they approve the expenditure of a portion of their available money on a project they will have to forego spending it on another project. The minimum attractive rate of return should actually be the "opportunity" rate of return the

state could make by investing its money in the most effective project. To do this would require a comparison of all possible projects to determine those with the highest rates of return. This, of course, is not practical; so the state must make this type of comparison based on money available in a specific time period. This means that the minimum rate of return has the potential to change and should be periodically updated. It is this technique that has brought on the requirement of cost effective studies in many government cost control centers and one of the reasons life cycle analysis must be used in future decisions. The choice of the minimum rate of return has a great influence on decision making at all levels.

The comparison of more than two alternatives can be accomplished more effectively using the "rate of return on the investment" technique. A basic difference in using the rate of return on the investment concept to evaluate an alternative, rather than a fixed rate of return for comparison, is the forecasting of the benefits derived from the investment. To determine the rate of return on any investment all of the costs must be forecasted, and in addition to this, a forecast of all of the benefits must also be predicted. If these can be forecasted, this technique gives the dicision-maker a better index to evaluate the investment with any alternative investments rather than just the alternatives to satisfy a specific need. The additional time and effort are usually worth while in over-all optimization of resources. The forecasting of benefits is usually more difficult than forecasting costs. Costs can be forecasted based on past experience or present cost. Benefits may be completely new and past experience or present benefits may not be available for forecasting.

5. The effect of inflation

The escalation of energy rates and the effect of inflation on predicted renewal cost as well as operating and maintenance costs have caused much debate on the accuracy and thus the validity of using life-cycle cost analysis. From a theoretical point of view the inflation rate and energy escalation figures must be included in life-cycle cost models to obtain the greatest degree of accuracy. From a practical point of view this presents many problems and questionable benefits.

Improved prediction of inflation rates is important for the overall development of the proposed life-cycle costing system, particularly for the forecasting and budgeting aspects. Recent changes in inflation rates have made the acceptance of the usual straight-line projections of historical inflation rates increasingly precarious.

However, if the organization inflates at the same rate as the alternative costs, the inflation is offsetting. In Figure 8 the theory can be understood easier by looking at a company investing a certain number of dollars, $C, at year zero in a piece of equipment having a life of y years. In y years the company would have to pay $C+$A for the renewal. However, if the company's product has inflated at the same rate, the X number of its products that produced a profit of $C in the year zero will produce a profit of $C+$A at the year y. Likewise, if the tax dollars increase at the same rate as inflation, the government studies will automatically include inflation. If there is a variation in the tax dollar increase, it is likely to be greater than the inflation rate.

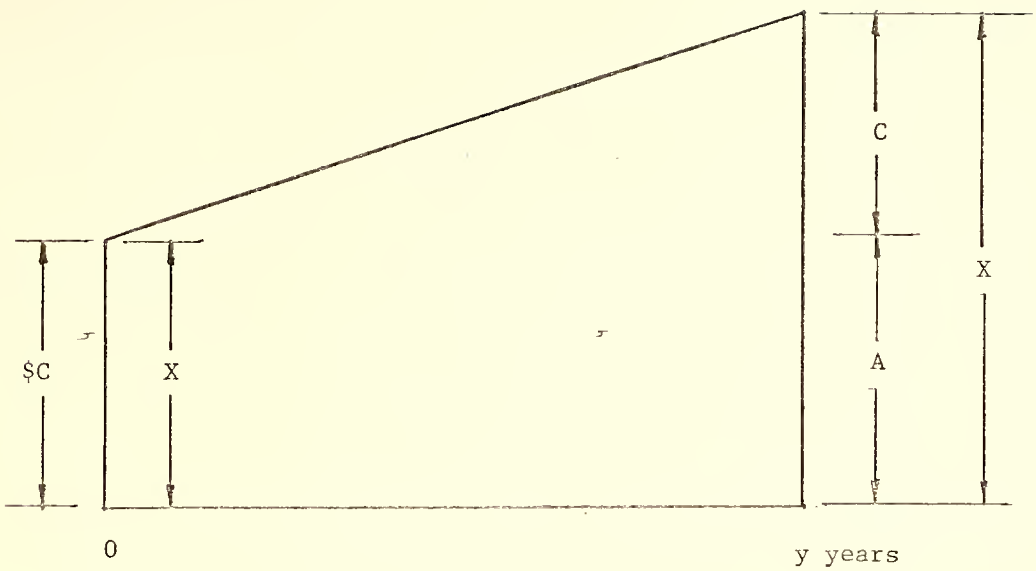

FIGURE 8: EFFECT OF INFLATION ON PRODUCT PRODUCTION

Source: Life Cycle Cost-Benefit Analysis Manual, KG Associates, 1975

If it is assumed that the organization's position does not inflate with normal inflation, it is necessary to forecast the variation. The effect of inflation will make the renewal costs either higher or lower. It will also be necessary to forecast the time period the alternatives will be needed. The model can then be constructed to reflect these two forecasts.

Since these models are primarily used to show the relative difference between alternatives, the effect of inflation is usually not significant. Also in the real life situation the renewal of

alternatives rarely follows the forecast. Decision-makers take advantage of the cyclic trends of inflation and if possible renew equipment when the cycle is on the low side of the trend line.

Another point to consider is that forecasts in the future are less significant with higher interest rates and longer periods of time than are short range forecasts and comparisons involving low interest rates. This assumption is one of the limitations involved in using these models for decision making. The actual sensitivity of this assumption can be determined by making an analysis with different interest rates and with different forecasts of lives for the alternatives. This is desirable if there is some doubt about the assumption being valid. The limitation may bother some people and make them doubtful of the value of the use of economic models for decision making. However, one should always remember what the alternative methods of evaluation are before deciding that this limitation is critical. In many cases the only other alternative is one of intuition, which has greater limitations.

In the federal government when using the present worth of analysis to do tradeoff studies on the comparisons of items, it is not valid to apply expected rates to cost data. The Office of Management and Budget has listed the following as reasons for this decision:

> The discount rate specified by OMB is a "real" rate; that is, it has been adjusted to remove the effect of inflation. Use of this real discount rate with costs that have been adjusted for inflation has the effect of reducing the discount

rate. This reduction in the effective discount rate, in turn, can erroneously alter the ranking of alternatives by increasing the present value of costs that will occur in the distant future.

Techniques for projecting overall price level changes for future years yield results that are subject to substantial error.

Use of inflation adjusted cost data would entail projection of nominal interest rates for each of the future years. Techniques that accomplish this are not in general use and involve substantial error terms.

Energy escalation figures may increase or decrease more rapidly than the general rate of inflation, and are important to consider in cost projections and analysis of alternatives on short term basis. If an analysis is performed taking into account energy escalation it should be done one of two ways.

1. Project the probable increase in price for the energy, and adjust this value in accordance with the projected change in the price level of other resources.

2. Perform an analysis in constant dollars, ignoring the consequences of relative price changes for the energy. Test the ranking of the alternatives from this analysis for the effect of relative price change for the energy, given a probability of that price change occurring. Interpret the changes in ranking with respect to the probability of the price change actually happening.

Again the federal government feels the second procedure is both analytically superior and easier to implement because it does not involve the uncertainties arising from projecting price change for all resources. This is particularly important because when using life-cycle cost analysis the basic cost of energy to manufacture a product is taken into account rather than just the energy used to construct the building.

Another point to consider is that as costs escalate the benefits derived from the use of an item are also changing. Unless there is an extreme variance from the normal situation, the benefits should escalate at approximately the same rate as the costs escalate. By using a constant dollar approach to life-cycle cost analysis both the cost and the benefits are put on an equivalent basis.

6. What life span should be used?

It is not possible to say exactly how long a school building or any building will last. However, when doing life cycle costing studies for indefinite periods, the total life span is not important as long as it is over 40 years. Figure 9 reveals that the effect of the initial construction cost to the uniform annual cost changes very little when time is extended beyond 40 years.

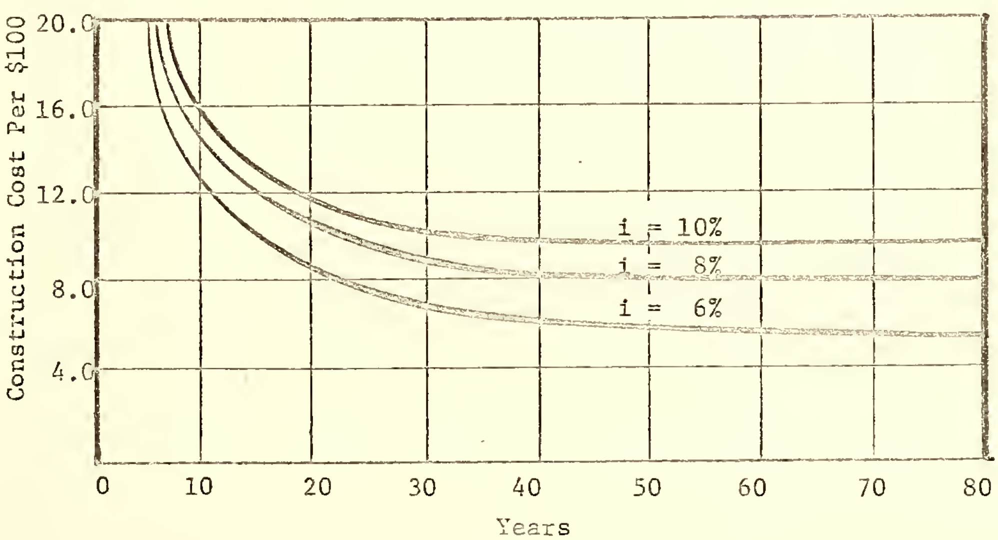

FIGURE 9: EFFECT OF TIME ON ANNUAL LIFE CYCLE COST

Source: "Life Cycle Cost, the Concept and Application in Conventional Design," United States Air Force, 1970

Since time has little effect on cost comparisons beyond the forty-year point, it seems reasonable to use the forty-year mark as the maximum life span in those cases where it is not possible to clearly define the useful life of a building.

The assumption that a system will be used for an indefinite period of time becomes less significant as the interest rates increase and as the time period grows longer. Forecasts in the future are less significant with higher interest rates and longer periods of time than are short range forecasts and comparisons involving low interest rates. Assuming a need for an indefinite length of time makes it necessary to establish renewal costs in the future. The assumption is that all costs using current dollar values will repeat in the renewal, so that the Uniform Annual Cost remains the same regardless of the number of times an item is renewed.

7. Which method should be used?

Once an economic model has been constructed representing all the expenditures over the life of a building or system it can be evaluated by either the annual cost method or the present worth method. Since both will produce the correct results, the question arises as to which method should be used.

When the federal government first began exploring the use of life cycle costing, they primarily utilized the present worth method of analysis. However, after twenty years of experimenting, the government has decided that the annual cost method is more appropriate. For most situations, the General Services Administration states the reasons for

this selection in Volume I of their manual Life Cycle Costing in the Public Buildings Service.

> Annual costs are likely to be better understood than present worth cost since accounting conventions are tied to annual budgeting and cost comparisons rather than the time value of money.
>
> The sensitivity of the total cost of an alternative system to change is some cost component can be analyzed directly once annual costs are obtained. For example, the effect of a 50 percent increase in the price of a component or annual operating cost can be immediately determined by adding the assumed increase to other costs after they have been converted to annual cost.
>
> Annual cost for alternative systems of unequal life spans can be easily compared. In present worth analysis, by contrast, if the alternatives under comparison have different estimated lives, a time period common to the economic life of all alternatives must be chosen which will not bias the outcome.

The construction of the original economic model appears to be the primary reason for selecting the annual cost method of analysis. Once a numeric answer is obtained with either method it can quickly be converted from one form to the other. An answer in annual cost terms can be converted to present worth terms by multiplying the answer by the proper interest factor. In this case, the annual cost could be multiplied by a Uniform Present Worth Factor (UPW) to determine its present worth. An answer in terms of present worth could be multiplied by the Uniform Capital Recovery Factor (UCR) to determine an annual cost.

8. Who should be involved in a life cycle cost study?

It has been pointed out in the earlier discussion that life cycle analysis can and should be used at all decision levels involving the life of a school facility. This means that many different people are

going to have to understand the concepts of life cycle costing. Herein lies one of the immediate and crucial problems to the progress of life cycle costing - the ability to understand the concept. In a report to the Department of Health, Education and Welfare which covered the evaluation of life cycle costing for health facilities the following statement appeared.

> "One of the greatest problems is the general lack of awareness of the concept of almost all facility decision makers. Possibly, the single most important step which can be taken in the immediate future is to launch a major education effort to increase the awareness of, interest in, and proper use of the concept.--
> ---------It will require a multi-phased effort to stimulate a significant increase in the awareness of the life cycle cost analysis concept."

This same "lack of awareness of the concept" exists within the educational field and must be dealt with before solutions can be found for any of the problems confronting the use of life cycle costing. The architectural and engineering professions also lack sufficient knowledge in the fundamental and proper use of the concept.

Both professions must be educated in life-cycle cost analysis concepts if any meaningful judgements are to be made using this tool. At present, non of the state universities, in either the education or architecture curricula, offer any instruction regarding the concepts or proper use of life cycle cost analysis. Furthermore, very few workshops and very limited literature have been available for professionals already in the field

When the influences of early planning and design decisions are analyzed, one realizes that it is important that each person involved in the building process understands the proper use of life cycle costing. Decision makers must be made to realize that life cycle costing is not just the solving of an equation or a simple computer print-out, but that a keen understanding of the variables involved is necessary in order to select the most economical alternative.

Recommendations for the Process and Procedure of Determining Life Cycle Cost-Benefit for Educational Facilities

Although the concepts of life-cycle costing are not new, there is a lack of awareness as to their proper use in both the education and building professions. Even though the mechanics of the concept are not difficult, it will take a certain amount of preparation and education to implement the process on a state wide basis and expect to achieve realistic benefits. The incorrect use of the concept could produce expensive mistakes. The primary factors producing these problems are:

1. The lack of accurate and readily available data in the areas of initial building systems cost, operating cost, maintenance cost and renewal cost.
2. The limited number of professional architects and engineers in the state who understand and can perform life cycle cost-benefit studies.
3. The small number of official decision makers associated with the educational field who are familiar with the correct interpretation of a life cycle cost-benefit study.

4. The lack of a clearly defined policy by the state as to what should be included in an analysis; type of analysis; format of analysis and amount of additional fee to be paid for the analysis.

In order to overcome these factors and successfully implement life cycle cost-benefit analysis of the designs, constructions and operation of educational facilities, the following general and specific recommendations are made:

GENERAL RECOMMENDATIONS:

1. Establish a system of data collection that would include initial construction cost, annual operating and maintenance cost and life spans of construction materials and systems.

2. Establish a more detailed and specific procedure and uniform format for architects and engineers to follow when submitting a life cycle cost-benefit study to school officials.

3. Establish an additional fee to pay for the cost of performing a life cycle cost-benefit analysis.

4. Establish a procedure by which the Office of Educational Facilities Construction can review and approve each life cycle cost study before it is submitted to local school officials.

5. Begin a program to educate school personnel in the use of life cycle cost-benefit analysis. This should include:

   A. Sponsor a series of life cycle cost-benefit analysis workshops throughout the state.

   B. Develop a manual on the use of life cycle cost-benefit analysis in regard to school facilities.

   C. Establish a clearinghouse to disseminate new technical information bulletins, handbooks and texts on life cycle cost-benefit analysis.

   D. Establish a means so school officials can easily obtain assistance in answering specific life cycle cost-benefit analysis problems.

6. Encourage the architectural and engineering societies to establish a plan to educate members of their professions in the correct use of life cycle cost-benefit analysis.

SPECIFIC RECOMMENDATIONS:

1. Use the annual cost method of analysis on all studies.

2. The annual cost model should include:

   A. Initial cost of the building.

   B. Estimated annual operating cost based on expected energy consumption as determined by approved methods of calculations.

C. Annual estimated maintenance cost as determined by school officials.

D. Estimated renewal cost as determined by school officials.

3. The annual cost models should be set up in the following manner:

   Annual Cost = Initial Building Cost (UCR;y;i) + Annual Operating & Maintenance Cost + Renewal Cost (USF;y;i)*

   *There may be renewal cost on several components and they would each be added to the model.

4. Perform an analysis on at least two individual building designs or at least two energy systems associated with the same building.

5. Perform all energy consumption calculations by the same method for any particular building.

6. Use a 40-year life span for the analysis.

7. Use a rate of return of 10%. This must be updated on a yearly basis.

8. Adopt suggested modifications to the DGS Florida Life Cycle Cost Analysis Manual for use in school facilities.

   Note: Suggested modifications are contained in a separate document.

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GLOSSARY

Alternatives: Different courses of action or systems that will satisfy objectives and goals.

Book Value: First cost minus depreciation.

Cost: Cash expenditure or equivalence at a specific time.

Cost Center: Any department, project, or activity with a specific budget. Separate cost centers are most appropriate when the size, character, and relationship of the overhead costs of the activities differ substantially.

Interest: A ratio of the amount paid for using resources for a given period of time to the total investment.

Life Cycle Cost: Total equivalent cost.

Minimum Attractive Rate of Return: Reflects the cost of using resources and the risk that the project may fail to produce the expected results. The risk portion of the minimum attractive rate of return varies with different cost centers and even with projects within cost centers.

Opportunity Rate: That rate of return which the organization could make by investing its resources in the most beneficial (profitable) projects to the limit of the resources available.

Sensitivity: The relative effect a variable has on the decision criterion.

Sunk Cost: Past costs which cannot be charged to any of the alternatives being considered and is irrelevant.

System: A component or group of components that will accomplish the objective.

Time Value of Money: Recognition that all organizations have limited resources (finances, people, facilities, equipment) and that the commitment of these to a project precludes their use for any other investment. Whether internal resources are used, or borrowed ones are used, the interest which these resources could produce is a cost to the project.

APPENDIX

2% Interest Factors

Year Y	SCA P-F	SPW F-P	UCA A-F	USF F-A	UCR P-A	UPW A-P
1	1.020	.9804	1.000	1.000	1.020	0.980
2	1.040	.9612	2.020	.4951	.5151	1.942
3	1.061	.9423	3.060	.3268	.3468	2.884
4	1.082	.9238	4.122	.2426	.2626	3.808
5	1.104	.9057	5.204	.1922	.2122	4.713
6	1.126	.8880	6.308	.1585	.1785	5.601
7	1.149	.8706	7.434	.1345	.1545	6.472
8	1.172	.8535	8.583	.1165	.1365	7.325
9	1.195	.8368	9.755	.1025	.1225	8.162
10	1.219	.8203	10.95	.0913	.1113	8.983
11	1.243	.8043	12.17	.0822	.1022	9.787
12	1.268	.7885	13.41	.0746	.0946	10.58
13	1.294	.7730	14.68	.0681	.0881	11.35
14	1.319	.7579	15.97	.0626	.0826	12.11
15	1.346	.7430	17.29	.0578	.0778	12.85
16	1.373	.7284	18.64	.0537	.0737	13.58
17	1.400	.7142	20.01	.0500	.0700	14.29
18	1.428	.7002	21.41	.0467	.0667	14.99
19	1.457	.6864	22.84	.0438	.0638	15.68
20	1.486	.6730	24.30	.0412	.0612	16.35
21	1.516	.6600	25.78	.0388	.0588	17.01
22	1.546	.6468	27.30	.0366	.0566	17.66
23	1.577	.6342	28.85	.0347	.0547	18.29
24	1.608	.6217	30.42	.0329	.0529	18.91
25	1.641	.6100	32.03	.0312	.0512	19.52
30	1.811	.5521	40.57	.0247	.0447	22.40
35	2.000	.5000	49.99	.0200	.0400	25.00
40	2.208	.4529	60.40	.0166	.0366	27.36
45	2.438	.4102	71.89	.0139	.0339	29.49
50	2.692	.3715	84.58	.0118	.0318	31.42
60	3.281	.3048	114.1	.0088	.0288	34.76
70	4.000	.2500	150.0	.0067	.0267	37.50
80	4.875	.2051	193.8	.0052	.0252	39.75
90	5.943	.1683	247.2	.0041	.0241	41.59
100	7.245	.1380	312.2	.0032	.0232	43.10

4% Interest Factors

Year Y	SCA P-F	SPW F-P	UCA A-F	USF F-A	UCR P-A	UPW A-P
1	1.040	.9615	1.000	1.000	1.040	0.962
2	1.082	.9246	2.040	.4902	.5302	1.886
3	1.125	.8890	3.122	.3204	.3604	2.775
4	1.170	.8548	4.246	.2355	.2755	3.630
5	1.217	.8219	5.416	.1846	.2246	4.452
6	1.265	.7903	6.633	.1508	.1908	5.242
7	1.316	.7599	7.898	.1266	.1666	6.002
8	1.369	.7307	9.214	.1085	.1485	6.733
9	1.423	.7026	10.58	.0945	.1345	7.435
10	1.480	.6756	12.01	.0833	.1233	8.111
11	1.539	.6496	13.49	.0742	.1142	8.760
12	1.601	.6246	15.03	.0666	.1066	9.385
13	1.665	.6006	16.63	.0601	.1001	9.986
14	1.732	.5775	18.29	.0547	.0947	10.56
15	1.801	.5553	20.02	.0499	.0899	11.12
16	1.873	.5339	21.83	.0458	.0858	11.65
17	1.948	.5134	23.70	.0422	.0822	12.17
18	2.026	.4936	25.65	.0390	.0790	12.66
19	2.107	.4746	27.67	.0361	.0761	13.13
20	2.191	.4564	29.78	.0336	.0736	13.59
21	2.279	.4388	31.97	.0313	.0713	14.03
22	2.370	.4220	34.25	.0292	.0692	14.45
23	2.465	.4057	36.67	.0273	.0673	14.86
24	2.563	.3901	39.08	.0256	.0656	15.25
25	2.666	.3751	41.65	.0240	.0640	15.62
30	3.243	.0308	56.09	.0178	.0578	17.29
35	3.946	.2534	73.65	.0136	.0536	18.67
40	4.801	.2083	95.03	.0105	.0505	19.79
45	5.841	.1712	121.0	.0083	.0483	20.72
50	7.107	.1407	152.7	.0066	.0466	21.48
60	10.52	.0951	238.0	.0042	.0442	22.62
70	15.57	.0642	364.3	.0028	.0428	23.40
80	23.05	.0434	551.2	.0018	.0418	23.92
90	34.12	.0293	828.0	.0012	.0412	24.27
100	50.51	.0198	1238.	.0008	.0409	24.51

6% Interest Factors

Year Y	SCA P-F	SPW F-P	UCA A-F	USF F-A	UCR P-A	UPW A-P
1	1.060	.9434	1.000	1.000	1.060	0.943
2	1.124	.8900	2.060	.4854	.5454	1.833
3	1.191	.8400	3.184	.3141	.3741	2.673
4	1.262	.7921	4.375	.2286	.2886	3.465
5	1.338	.7473	5.637	.1774	.2374	4.212
6	1.419	.7050	6.975	.1434	.2034	4.917
7	1.504	.6651	8.394	.1191	.1791	5.582
8	1.594	.6274	9.897	.1010	.1610	6.210
9	1.689	.5919	11.49	.0870	.1470	6.802
10	1.791	.5584	13.18	.0759	.1359	7.360
11	1.898	.5268	14.97	.0668	.1268	7.887
12	2.012	.4970	16.87	.0593	.1193	8.384
13	2.133	.4688	18.88	.0530	.1130	8.853
14	2.261	.4423	21.02	.0476	.1076	9.295
15	2.397	.4173	23.28	.0430	.1030	9.712
16	2.540	.3936	25.67	.0390	.0990	10.11
17	2.693	.3714	28.21	.0354	.0954	10.48
18	2.854	.3503	30.91	.0324	.0924	10.83
19	3.026	.3305	33.76	.0296	.0896	11.16
20	3.207	.3118	36.79	.0272	.0872	11.47
21	3.400	.2942	39.99	.0250	.0850	11.76
22	3.604	.2775	43.40	.0231	.0831	12.04
23	3.820	.2618	47.00	.0213	.0813	12.30
24	4.049	.2470	50.82	.0197	.0797	12.55
25	4.292	.2330	54.87	.0182	.0782	12.78
30	5.743	.1741	79.06	.0127	.0727	13.77
35	7.686	.1301	111.4	.0090	.0690	14.50
40	10.29	.0972	154.8	.0065	.0665	15.05
45	13.77	.0727	212.7	.0047	.0647	15.46
50	18.42	.0543	290.3	.0034	.0634	15.76
60	32.99	.0303	533.1	.0019	.0619	16.16
70	59.08	.0169	967.9	.0010	.0610	16.39
80	105.8	.0095	1747.	.0006	.0606	16.51
90	189.5	.0053	3141.	.0003	.0603	16.58
100	339.3	.0029	5638.	.0002	.0602	16.62

8% Interest Factors

Year Y	SCA P-F	SPW F-P	UCA A-F	USF F-A	UCR P-A	UPW A-P
1	1.080	.9259	1.000	1.000	1.080	0.926
2	1.166	.8573	2.080	.4808	.5608	1.783
3	1.260	.7938	3.246	.3080	.3880	2.577
4	1.360	.7350	4.506	.2219	.3019	3.312
5	1.469	.6806	5.867	.1705	.2505	3.993
6	1.587	.6302	7.336	.1363	.2163	4.623
7	1.714	.5835	8.923	.1121	.1921	5.206
8	1.851	.5403	10.64	.0940	.1740	5.747
9	1.999	.5002	12.49	.0801	.1601	6.247
10	2.159	.4632	14.49	.0690	.1490	6.710
11	2.332	.4289	16.65	.0601	.1401	7.139
12	2.518	.3971	18.98	.0527	.1327	7.536
13	2.720	.3677	21.50	.0465	.1265	7.904
14	2.937	.3405	24.22	.0413	.1213	8.244
15	3.172	.3152	27.15	.0368	.1168	8.559
16	3.426	.2919	30.32	.0330	.1130	8.851
17	3.700	.2703	33.75	.0396	.1096	9.122
18	3.996	.2502	37.45	.0267	.1067	9.372
19	4.316	.2317	41.45	.0241	.1041	9.604
20	4.661	.2145	45.76	.0219	.1019	9.818
21	5.034	.1987	50.42	.0198	.0998	10.02
22	5.437	.1839	55.46	.0180	.0980	10.20
23	5.871	.1703	60.89	.0164	.0964	10.37
24	6.341	.1577	66.77	.0150	.0950	10.53
25	6.848	.1460	73.11	.0137	.0937	10.68
30	10.06	.0994	113.3	.0088	.0888	11.26
35	14.79	.0676	172.3	.0058	.0858	11.66
40	21.73	.0460	259.1	.0039	.0839	11.93
45	31.92	.0313	386.5	.0025	.0826	12.11
50	46.90	.0213	573.7	.0017	.0817	12.23
60	101.3	.0099	1253.	.0008	.0808	12.38
70	218.6	.0046	2720.	.0004	.0804	12.44
80	472.0	.0021	5887.	.0002	.0802	12.47
90	1019.	.0010	12724.	.0001	.0801	12.49
100	2200.	.0005	27485.	.0000	.0800	12.49

10% Interest Factors

Year Y	SCA P-F	SPW F-P	UCA A-F	USF F-A	UCR P-A	UPW A-P
1	1.100	.9091	1.000	1.000	1.100	0.909
2	1.210	.8264	2.100	.4762	.5762	1.736
3	1.331	.7513	3.310	.3021	.4021	2.487
4	1.464	.6830	4.641	.2155	.3155	3.170
5	1.611	.6209	6.105	.1638	.2638	3.791
6	1.772	.5645	7.716	.1296	.2296	4.355
7	1.949	.5132	9.487	.1054	.2054	4.868
8	2.144	.4665	11.44	.0874	.1874	5.335
9	2.358	.4241	13.58	.0736	.1736	5.759
10	2.594	.3855	15.94	.0628	.1628	6.144
11	2.853	.3505	18.53	.0540	.1540	6.500
12	3.138	.3186	21.38	.0468	.1468	6.814
13	3.452	.2897	24.52	.0408	.1408	7.103
14	3.797	.2633	27.98	.0358	.1358	7.367
15	4.177	.2394	31.77	.0315	.1315	7.606
16	4.595	.2176	35.95	.0278	.1278	7.824
17	5.054	.1978	40.54	.0247	.1247	8.022
18	5.560	.1799	45.60	.0219	.1219	8.201
19	6.116	.1635	51.16	.0196	.1196	8.365
20	6.727	.1486	57.28	.0175	.1175	8.514
21	7.400	.1351	64.00	.0156	.1156	8.649
22	8.140	.1228	71.40	.0140	.1140	8.772
23	8.954	.1117	79.54	.0126	.1126	8.883
24	9.850	.1015	88.50	.0113	.1113	8.985
25	10.84	.0923	98.35	.0102	.1102	9.077
30	17.50	.0573	164.5	.0061	.1061	9.427
35	28.10	.0356	271.0	.0037	.1037	9.644
40	45.26	.0221	442.6	.0023	.1023	9.779
45	72.89	.0137	718.9	.0014	.1014	9.863
50	117.4	.0085	1164.	.0009	.1009	9.915
60	304.5	.0033	3035.	.0003	.1003	9.967
70	789.7	.0013	7887.	.0001	.1001	9.987
80	2048.	.0005	20474.	.0001	.1001	9.995
90	5313.	.0002	53120.	.0000	.1000	9.999

12% Interest Factors

YEAR Y	SCA P-F	SPW F-P	UCA A-F	USF F-A	UCR P-A	UPW A-P
1	1.120	.8929	1.000	1.000	1.120	0.893
2	1.254	.7972	2.120	.4717	.5917	1.690
3	1.405	.7118	3.374	.2963	.4164	2.402
4	1.574	.6355	4.779	.2092	.3292	3.037
5	1.762	.5674	6.353	.1574	.2774	3.605
6	1.974	.5066	8.115	.1232	.2432	4.111
7	2.211	.4523	10.09	.0991	.2191	4.564
8	2.476	.4039	12.30	.0813	.2013	4.968
9	2.773	.3606	14.78	.0677	.1877	5.328
10	3.106	.3220	17.55	.0570	.1770	5.650
11	3.479	.2875	20.66	.0484	.1684	5.938
12	3.896	.2567	24.13	.0414	.1614	6.194
13	4.363	.2292	28.03	.0357	.1557	6.424
14	4.887	.2046	32.40	.0309	.1509	6.628
15	5.474	.1827	37.28	.0269	.1469	6.811
16	6.130	.1631	42.75	.0234	.1434	6.974
17	6.866	.1456	48.88	.0205	.1405	7.120
18	7.690	.1300	55.75	.0179	.1379	7.250
19	8.613	.1161	63.44	.0158	.1358	7.366
20	9.646	.1037	72.05	.0139	.1339	7.469
21	10.80	.0926	81.70	.0122	.1322	7.562
22	12.10	.0826	92.50	.0108	.1308	7.645
23	13.55	.0738	104.6	.0096	.1296	7.718
24	15.18	.0659	118.2	.0085	.1285	7.784
25	17.00	.0588	133.3	.0075	.1275	7.843
30	29.96	.0334	241.3	.0041	.1241	8.055
35	52.80	.0189	431.7	.0023	.1223	8.176
40	93.05	.0107	767.1	.0013	.1213	8.244
45	164.0	.0061	1358.	.0007	.1207	8.283
50	289.0	.0035	2400.	.0004	.1204	8.304
60	897.6	.0011	7472.	.0001	.1201	8.324
70	2788.	.0004	23223.	.0000	.1200	8.330

15% Interest Factors

Year Y	SCA P-F	SPW F-P	UCA A-F	USF F-A	UCR P-A	UPW A-P
1	1.150	.8696	1.000	1.000	1.150	0.870
2	1.322	.7561	2.150	.4651	.6151	1.626
3	1.521	.6575	3.472	.2880	.4380	2.283
4	1.749	.5718	4.993	.2003	.3503	2.855
5	2.011	.4972	6.742	.1483	.2983	3.352
6	2.313	.4323	8.754	.1142	.2642	3.784
7	2.660	.3759	11.07	.0904	.2404	4.160
8	3.059	.3269	13.73	.0729	.2229	4.487
9	3.518	.2843	16.79	.0596	.2096	4.772
10	4.046	.2472	20.30	.0493	.1993	5.019
11	4.652	.2149	24.35	.0411	.1911	5.234
12	5.350	.1869	29.00	.0345	.1845	5.421
13	6.153	.1625	34.35	.0291	.1791	5.583
14	7.076	.1413	40.51	.0247	.1747	5.724
15	8.137	.1229	47.58	.0210	.1710	5.847
16	9.358	.1069	55.72	.0180	.1680	5.954
17	10.76	.0929	65.08	.0154	.1654	6.047
18	12.38	.0808	75.84	.0132	.1632	6.128
19	14.23	.0703	88.21	.0113	.1613	6.198
20	16.37	.0611	102.4	.0098	.1598	6.259
21	18.82	.0531	118.8	.0084	.1584	6.312
22	21.65	.0462	137.6	.0073	.1573	6.359
23	24.89	.0402	159.3	.0063	.1563	6.399
24	28.63	.0349	184.2	.0054	.1554	6.434
25	32.92	.0304	212.8	.0047	.1547	6.464
30	66.21	.0151	434.7	.0023	.1523	6.566
35	133.2	.0075	881.2	.0011	.1511	6.617
40	267.9	.0037	1779.	.0006	.1506	6.642
45	538.8	.0019	3585.	.0003	.1503	6.654
50	1083.	.0009	7218.	.0001	.1501	6.661
60	4384.	.0002	29219.	.0000	.1500	6.665

20% Interest Factors

YEAR Y	SCA P-F	SPW F-P	UCA A-F	USF F-A	UCR P-A	UPW A-P
1	1.200	.8333	1.000	1.000	1.200	0.833
2	1.400	.6944	2.200	.4546	.6546	1.528
3	1.728	.5787	3.640	.2747	.4747	2.106
4	2.074	.4823	5.368	.1863	.3863	2.589
5	2.488	.4019	7.442	.1344	.3344	2.991
6	2.986	.3349	9.930	.1007	.3007	3.326
7	3.583	.2791	12.92	.0774	.2774	3.605
8	4.300	.2326	16.50	.0606	.2606	3.837
9	5.160	.1938	20.80	.0481	.2481	4.031
10	6.192	.1615	25.96	.0385	.2385	4.192
11	7.430	.1346	23.15	.0311	.2311	4.327
12	8.916	.1122	39.58	.0253	.2253	4.439
13	10.70	.0935	48.50	.0206	.2206	4.533
14	12.84	.0779	59.20	.0169	.2169	4.611
15	15.41	.0650	72.04	.0139	.2139	4.675
16	18.49	.0541	87.44	.0114	.2114	4.730
17	22.19	.0451	105.9	.0094	.2094	4.775
18	26.62	.0376	128.1	.0078	.2078	4.812
19	31.95	.0313	154.7	.0065	.2065	4.843
20	38.39	.0261	186.7	.0054	.2054	4.870
21	46.01	.0217	225.0	.0044	.2044	4.891
22	55.21	.0181	271.0	.0037	.2037	4.909
23	66.25	.0151	326.2	.0031	.2031	4.925
24	79.50	.0126	392.5	.0026	.2026	4.937
25	95.40	.0105	472.0	.0021	.2021	4.948
30	237.4	.0042	1182.	.0009	.2009	4.979
35	590.7	.0017	2948.	.0003	.2003	4.992
40	1470.	.0007	7344.	.0001	.2001	4.997
45	3657.	.0003	18281.	.0001	.2001	4.999
50	9100.	.0001	45497.	.0000	.2000	4.999

25% Interest Factors

YEAR Y	SCA P-F	SPW F-P	UCA A-F	USF F-A	UCR P-A	UPW A-P
1	1.250	.8000	1.000	1.000	1.250	0.800
2	1.562	.6400	2.250	.4444	.6944	1.440
3	1.953	.5120	3.812	.2623	.5123	1.952
4	2.441	.4096	5.766	.1734	.4234	2.362
5	3.052	.3277	8.207	.1219	.3719	2.689
6	3.815	.2621	11.26	.0888	.3388	2.951
7	4.768	.2097	15.07	.0663	.3163	3.161
8	5.960	.1678	19.84	.0504	.3004	3.329
9	7.451	.1342	25.80	.0388	.2888	3.463
10	9.313	.1074	33.25	.0301	.2801	3.571
11	11.64	.0859	42.57	.0235	.2735	3.656
12	14.55	.0687	54.21	.0185	.2685	3.725
13	18.19	.0550	68.76	.0145	.2645	3.780
14	22.74	.0440	86.95	.0115	.2615	3.824
15	28.42	.0352	109.7	.0091	.2591	3.859
16	35.53	.0281	138.1	.0072	.2572	3.887
17	44.41	.0225	173.6	.0058	.2558	3.910
18	55.51	.0180	218.0	.0046	.2546	3.928
19	69.39	.0144	273.6	.0037	.2537	3.942
20	86.74	.0115	342.9	.0029	.2529	3.954
21	108.4	.0092	429.7	.0023	.2523	3.963
22	135.5	.0074	538.1	.0019	.2519	3.970
23	169.4	.0059	673.6	.0015	.2515	3.976
24	211.8	.0047	843.0	.0012	.2512	3.981
25	264.7	.0038	1055.	.0010	.2510	3.985
30	807.8	.0012	3227.	.0003	.2503	3.995
35	2465.	.0004	9857.	.0001	.2501	3.998
40	7523.	.0001	30089.	.0000	.2500	3.999

30% Interest Factors

YEAR Y	SCA P-F	SPW F-P	UCA A-F	USF F-A	UCR P-A	UPW A-P
1	1.300	.7692	1.000	1.000	1.300	0.769
2	1.690	.5917	2.300	.4348	.7348	1.361
3	2.197	.4552	3.990	.2506	.5506	1.816
4	2.856	.3501	6.187	.1616	.4616	2.166
5	3.713	.2693	9.043	.1106	.4106	2.436
6	4.827	.2072	12.76	.0784	.3784	2.643
7	6.275	.1594	17.58	.0569	.3569	2.802
8	8.157	.1226	23.86	.0419	.3419	2.925
9	10.60	.0943	32.02	.0312	.3312	3.019
10	13.79	.0725	42.62	.0235	.3235	3.092
11	17.92	.0558	56.41	.0177	.3177	3.147
12	23.30	.0429	74.33	.0135	.3135	3.190
13	30.29	.0330	97.63	.0102	.3102	3.223
14	39.37	.0254	127.9	.0078	.3078	3.249
15	51.19	.0195	167.3	.0060	.3060	3.268
16	66.54	.0150	218.5	.0046	.3046	3.283
17	86.50	.0116	285.0	.0035	.3035	3.295
18	112.5	.0089	371.5	.0027	.3027	3.304
19	146.2	.0068	484.0	.0021	.3021	3.311
20	190.1	.0053	630.2	.0016	.3016	3.316
21	247.1	.0040	820.2	.0012	.3012	3.320
22	321.2	.0031	1067.	.0009	.3009	3.323
23	417.5	.0024	1388.	.0007	.3007	3.325
24	542.8	.0018	1806.	.0006	.3006	3.327
25	705.6	.0014	2349.	.0004	.3004	3.329

40% Interest Factors

YEAR Y	SCA P-F	SPW F-P	UCA A-F	USF F-A	UCR P-A	UPW A-P
1	1.400	.7143	1.000	1.000	1.400	0.714
2	1.960	.5102	2.400	.4167	.8167	1.224
3	2.744	.3644	4.360	.2294	.6294	1.589
4	3.842	.2603	7.104	.1408	.5408	1.849
5	5.378	.1859	10.95	.0914	.4914	2.035
6	7.530	.1328	16.32	.0613	.4613	2.168
7	10.54	.0950	23.85	.0419	.4419	2.263
8	14.76	.0678	34.40	.0291	.4291	2.331
9	20.66	.0484	49.15	.0203	.4203	2.379
10	28.93	.0346	69.81	.0143	.4143	2.414
11	40.50	.0247	98.74	.0101	.4101	2.438
12	56.69	.0176	139.2	.0072	.4072	2.456
13	79.37	.0126	195.9	.0051	.4051	2.469
14	111.1	.0090	275.3	.0036	.4036	2.478
15	155.6	.0064	386.4	.0026	.4026	2.484
16	217.8	.0046	542.0	.0019	.4019	2.489
17	304.9	.0033	759.8	.0013	.4013	2.492
18	426.9	.0023	1065.	.0009	.4009	2.494
19	597.6	.0017	1492.	.0007	.4007	2.496
20	836.7	.0012	2089.	.0005	.4005	2.497
21	1171.	.0009	2926.	.0003	.4003	2.498
22	1640.	.0006	4097.	.0002	.4002	2.498
23	2296.	.0004	5737.	.0002	.4002	2.499
24	3214.	.0003	8033.	.0001	.4001	2.499
25	4500.	.0002	11247.	.0001	.4001	2.499

50% Interest Factors

YEAR Y	SCA P-F	SPW F-P	UCA A-F	USF F-A	UCR P-A	UPW A-P
1	1.500	.6667	1.000	.1000	1.500	0.667
2	2.250	.4444	2.500	.4000	.9000	1.111
3	3.375	.2963	4.750	.2105	.7105	1.407
4	5.062	.1975	8.125	.1231	.6231	1.605
5	7.594	.1317	13.19	.0758	.5758	1.737
6	11.39	.0878	20.78	.0481	.5481	1.824
7	17.09	.0585	32.17	.0311	.5311	1.883
8	25.63	.0390	49.26	.0203	.5203	1.922
9	38.44	.0260	74.89	.0134	.5134	1.948
10	57.67	.0173	113.3	.0088	.5088	1.965
11	86.50	.0116	171.0	.0059	.5059	1.977
12	129.7	.0077	257.5	.0039	.5039	1.985
13	194.6	.0051	387.3	.0026	.5026	1.990
14	292.0	.0034	581.9	.0017	.5017	1.993
15	437.9	.0023	873.8	.0011	.5011	1.995
16	656.8	.0015	1312.	.0008	.5008	1.997
17	985.3	.0010	1969.	.0005	.5005	1.998
18	1478.	.0007	2954.	.0003	.5003	1.999
19	2217.	.0005	4432.	.0002	.5002	1.999
20	3325.	.0003	6649.	.0002	.5002	1.999

ANALYSES AND RECOMMENDATIONS

RELATED TO PUBLIC SCHOOL CONSTRUCTION

Section III - RECOMMENDED REVISIONS TO CHAPTER 6A-2, EDUCATIONAL FACILITIES CONSTRUCTION

RECOMMENDED REVISIONS TO CHAPTER 6A-2, EDUCATIONAL FACILITIES CONSTRUCTION

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III. Recommended Revisions to Chapter 6A-2, Educational Facilities Construction

Introduction

It is recognized that the Regulations, Chapter 6A-2, Educational Facilities Construction, are authorized by Florida Law and as such cannot be revised without careful consideration and review. For this reason an attempt has been made to include only those recommendations that appear to be consistent with the purpose and content of the current Regulations.

Where possible the recommendations are worded as they might appear in the final document; others are in the form of general statements and discussions. Note recommendations are arranged in the sequence they occur in the current Regulations.

1. <u>It is recommended that consideration be given to relocating 6A-2.32 through 6A-2.40 in Part III of the Regulations</u>.

Sections 6A-2.03 through 6A-2.31 preceding 6A-2.32 - 6A-2.40 appear to be procedural instructions or requirements directly related to the conduct of the participants involved in the total building operation.

While Sections 6A-2.32 through 6A-2.40 might be termed procedural in the sense that they relate to the building design process (or requirements), they relate specifically to the building facility itself, not the individuals responsible for producing the building.

2. It is recommended that Section 6A-2.36, ACOUSTICAL TREATMENT, be made more definitive by specifying allowable noise levels.

No attempt is made here to specify allowable noise levels. On the assumption that further study of this subject may be needed, this recommendation is repeated in Section VI, Recommendations for Additional Studies.

3. It is recommended that the title of Part III, "State Uniform Building Code" be changed to read "State Educational Facilities Building Code."

This code applies specifically to the construction of educational facilities and not general construction throughout the state; therefore the title seems misleading.

The term "Uniform Building Code" has long been identified throughout the building industry as a well-known code used in many areas of the United States. It is, of course, an entirely different document.

Finally, it is understood that efforts are underway to develop and adopt a uniform state building code; whether such a code is adopted or not, references to "Uniform Building Code" will undoubtedly lead to further confusion.

4. It is recommended that "ASHRAE Standard 90-75" be added to the list of codes enumerated under 6A-2.45(5).

It is not possible to discuss fully here all of the ramifications of ASHRAE Standard 90-75; numerous references to 90-75 are made throughout this report and identify various portions and ways in which

the Standard should be utilized.

Very briefly the purpose of ASHRAE Standard 90-75 "is to provide design requirements which will improve utilization of energy in new buildings." For further discussion refer particularly to Section I of this report covering Prototype Design Criteria and Energy Conservation.

5. <u>It is recommended that 6A-2.63b(6) be changed from "...at not less than sixty (60) plus or minus five (5) percent relative humidity..." to read "...at not more than sixty-five (65) percent relative humidity..."</u>

Refer to the previous discussion of this recommendation (page I-7).

6. <u>It is recommended that consideration be given to reorganizing and re-writing 6A-2.65 Electrical illumination and lighting as discussed below:</u>

Consideration should be given to separating Electrical from Illumination and Lighting, preferably by creating separate sections. There is reason to believe that additional information should be added under Electrical (ref. Sect. VI Recommendations for Additional Study), as well as adding to Illumination and Lighting. While the subjects are certainly related, the kind of information required is quite different.

A major reason for proposing modifications and additions to Illumination and Lighting requirements is to conserve manufactured energy by providing illumination in classrooms utilizing a combination of daylight (solar, sky and reflected) and electrical lighting.

General Classroom Illumination

Illumination in general classrooms utilizing natural light should be designed to provide seventy (70) minimum horizontal foot-candles in the work area with at least forty (40) foot candles maintained average available from electric lighting in spaces used primarily during daylight hours. Classrooms used for normal class-room teaching in the evening should have seventy (70) foot candles maintained average from electric lighting available. Classrooms used at night for other than normal teaching-learning activities should have forty (40) foot candles minimum maintained average electric lighting systems.

Visual performance should be the criterion for lighting design in classrooms where the tasks are predominantly affected by veiling reflections. Where possible, task oriented lighting should be provided based on the Equivalent Sphere Illumination (ESI) recommended in the current I. E.S. Lighting Handbook, 5th edition. Where task oriented lighting is not desirable, a general classroom should have a minimum ESI rating of 50 ESI as determined by the I.E.S. A minimum of 25 ESI should be available from the electric lighting system for classes used predominantly for daytime teaching-learning.

Based on the above recommendations, 6A-2.65(2) would require modifications and additions to include general classrooms utilizing daylight as a primary or supplementary light source.

Daylight

When daylight is to be used in the primary lighting system, the minimum expected daylight in the building should be calculated for

the building operation cycle and integrated into the electric lighting calculations. This can be done by using the daylight design and calculation procedures given in the Recommended Practice of Daylighting (Illuminating Engineering, Vol. LVII, No. 8, August, 1962 and RE-5 Daylighting) available from I.E.S., 345 East 47th St., N.Y., N.Y. 10017), The LOF Daylighting Guide, or the CIE Daylighting Guide. When daylight is used as a supplementary light source, the electric lighting system can be designed independently of the daylight system, but adequate switching must be designed into the electric lighting when available. This may be done by automatic or prescribed manual control, by dimming, or complete cut off of the electric sources not needed to maintain satisfactory visual performance. This energy savings trade off should be included in FLEET or BIN in the diversity factor and in any other annual energy calculation technique.

Whether considered as a primary or secondary source, daylight utilization should be designed in accordance with the Recommended Practice of Daylighting. This practice includes recommendations for direct glare control, architectural design, calculation procedures and availability of daylight.

Where adequate local information is not available to determine daylight cycles, 500 foot candles incident on the window from an overcast sky should be used to determine the minimum daylight distribution within the classrooms. ESI distribution from daylight should be computed in accordance with the I.E.S. Daylight Committee recommendations. The daylighting system should be designed to provide as much of the required ESI as is justifiable based on Life Cycle Cost Benefit analysis.

7. It is recommended that the following be added to 6A-2.66: "(g) Ventilating systems for spaces listed in (d), (e) and (f) above shall meet the requirements of 'Industrial Ventilation, Manual of Recommended Practice' published by the American Conference of Governmental Industrial Hygienists."

The document listed above gives specific recommendations for the special conditions in (d), (e) and (f). Note the addition would occur at the end of 6A-2.66 on page 62A of the Regulations.

8. It is recommended that 6A-2.67(1) be changed to read: "Roof construction shall have a U-factor of not more than seventy-five thousandths (0.075) for solid portions of the roof, and an overall U_o-factor of not more than 0.12."

Refer to the previous discussion of this recommendation (page I-3).

9. It is recommended that 6A-2.67(2) be changed to read as follows: "(2) Exterior wall construction, excluding glass areas, shall have a U-factor of not more than thirty-five hundredths (0.35) and an overall heat gain, including glass areas, of not more than 30 Btu/sq.ft.(hr.)."

Refer to the previous discussion of this recommendation (page I-4).

10. It is recommended that the following be added to 6A-2.67: "(3) Thermal insulation for all spaces and for ducts and piping shall meet the requirements of ASHRAE Standard 90-75."

Refer to previous discussion of this recommendation (page I-2).

ANALYSES AND RECOMMENDATIONS

RELATED TO PUBLIC SCHOOL CONSTRUCTION

Section IV - ALTERNATIVE BIDDING/BUILDING PROCEDURES

ALTERNATIVE BIDDING/BUILDING PROCEDURES

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INTRODUCTION

A building program is conceived upon the awareness of a need for physical facilities and is launched when the means to plan and construct those facilities become available. Among the many decisions which must be made by the owner in the course of a building program are those determining how the ultimate building goal will be approached. The gap between the realization of a need for a building and the fulfillment of that need with a tangible completed structure can be traversed in many ways. Choosing the most appropriate means for a specific project requires some understanding of the alternatives available.

An attempt will be made here to familiarize the reader with some of the methods and procedures useful to the realization of educational facilities. A further attempt will also be made to provide some guidelines to assist in choosing the optimum method for specific projects according to the conditions prevailing for those projects.

BUILDING TERMS, CONCEPTS AND PROCEDURES

In recent years new and useful concepts that promise improvement in the task of providing built environment have evolved. As with many new ideas they have also introduced their own language. One difficulty in discussing these new concepts is a lack of uniform definitions for many of the terms so freely utilized. The latest buzz words and phrases are often tossed back and forth between owners, architects, builders and others with no common understanding of their meaning. An attempt will not be made here to establish precise authoritative definitions for these terms, however, the following terms and concepts will be discussed as a means to aid in the understanding of the principles they embody and the useful application of those principles to a building program.

Lump Sum - Single Contract

Historically this has been the most common type of construction contract. Under this method plans and specifications must be completed in such detail that it is possible to determine in advance all that will be required to complete the entire project. Prospective contractors, or bidders as they are termed, are then invited to compete in preparation of firm proposals to construct the facilities for a single lump sum dollar amount. The lowest qualified proposal is generally accepted and a single contract including all the work is then entered into between the owner and successful bidder.

Positive Aspects of Lump Sum - Single Contract

1. The owner is assured of the entire cost before any construction contracts are let. He can exercise an option to abandon the project if he cannot provide sufficient funds for its completion, or he can have it redesigned to fit his budget before committing himself to any part of the construction.

2. One prime contractor means that there is but one responsibility for the construction process.

Negative Aspects of Lump Sum - Single Contract

1. The elapsed time between a realization of need for a building and its completion is usually longest for this method inasmuch as one phase cannot begin until the previous phase has been finished. All detailed construction documents must be completed before any bids can be entertained.

In times of rapidly increasing costs, time is very significant. At inflation rates such as we have recently experienced, each month's delay in letting building contracts can add more than $10,000 to the cost of a one million dollar project.

2. On large projects that require lengthy construction periods a lump sum bidder is forced to guess what certain of his costs may be - one, two, or even three years in the future - and commit himself to those costs today. Under these circumstances he is likely to play it safe and allow for the worst conditions, possibly resulting in an unnecessarily high bid.

3. Where projects are large, the bonding capacity required and risk involved is so great as to significantly reduce the possible qualified or interested bidders, thereby decreasing competition.

Lump Sum - Separate Contracts

This method differs for the lump sum - single contract method only in that bids are taken for separate work packages, usually at least four. In some states (New York and Ohio for example) it is a legal requirement for public work that a minimum of four separate bid packages be created; (1) General Work, (2) Plumbing and Drainage, (3) Heating, Ventilating and Air-Conditioning, and (4) Electrical Work. Normally bids are taken simultaneously for all the work packages. Separate prime contracts are then awarded to successful bidders for each of the packages.

Positive Aspects of Lump Sum - Separate Contracts

1. When all packages are bid at the same time the owner knows his total cost before committing himself to contracts for any part of it.

2. It is often possible to award contracts for some work packages immediately so that construction can begin. Other packages which did not produce satisfactory proposals or which show a need for revision to meet budget requirements can be rebid while work is in progress, thus preventing one facet of the work from delaying the entire project.

3. Overall cost savings are claimed over the single contract method because the General Contractor's fee for administering the work of principal subcontractors can be eliminated as they now bid and contract directly with the owner and are paid directly by him.

Negative Aspects of Lump Sum - Separate Contracts

1. Most of the disadvantages of time inherent in the single contract method apply to this method as well. The complete design and all contract documents must be prepared before any bids are taken.

2. Difficulty in coordinating the work of several prime contractors, additional administrative bookkeeping, and lack of a single party responsible for the entire construction process have been cited as negative aspects of this method. In areas where this method is the custom the task of coordinating the work of contractors and establishing the degree of responsibility among them has been assumed by the architect who normally furnishes this service.

Direct Negotiation

Under the process of direct negotiation a builder may be selected as soon as the nature and scope of a needed building facility is determined.

Direct negotiation entails the selection of a builder who can show evidence of capability for completing comparable construction in a satisfactory manner according to an acceptable time schedule. He shows that he has the necessary resources and reputation to indicate that the chances of his fulfilling contract requirements on time satisfactorily are good. A contract is then directly negotiated with the apparent best qualified bidder according to one of several fee arrangements:

A. Cost Plus a Percentage of Cost - Under this system the builder is paid all of his direct project related costs for labor, material, and services. He is paid in addition a fixed percentage of that cost as his profit. Overhead costs may be included in the percentage or they may be charged as part of the direct project costs.

B. Cost Plus a Fixed Fee - Under this system the builder is paid all of his direct project costs plus a fixed lump sum as profit rather than a percentage of cost. The lump sum fee may or may not include overhead costs.

C. Cost Plus Fixed Fee with Profit Sharing - To use this scheme a preliminary estimate of cost or target must be set and agreed to for the work. At the project's completion any savings

after costs and fee are paid will be divided between the owner and builder according to a previously agreed on formula.

Many variations of negotiated contracts can be worked out that provide rewards for economical construction or rapid completion. A decision to negotiate the construction contract is one that should be made only in consultation with the architect to determine that it is the most advantageous procedure under the prevailing project conditions.

Positive Aspects of Direct Negotiation

1. Construction can begin immediately. Site preparation can be started in the early planning stages. The total time required for planning and construction can be reduced significantly.

2. Changes are easily made as the project progresses because no prior commitment for specific materials and methods have been made. The owner has great opportunity for input because he can see partially completed work which may affect his judgement concerning subsequent work.

3. Where it is difficult to determine actual costs beforehand as in the case of renovating and remodeling work, this method assures that the owner will pay the cost only of actual work required. When a builder must estimate his future costs for a bid where many of those costs cannot be accurately pre-determined, he must condition his bid to cover all possible contingencies. If they do not occur his profit is increased.

Negative Aspects of Direct Negotiation

1. Total cost of the project is not known at the time construction begins.

2. Under the cost plus percentage scheme there is no incentive for the contractor to minimize costs. The more it costs the greater his total profit. Efficiency in prosecuting the work may suffer.

3. Unless there are strict time limitations the contractor may use his resources of labor and equipment in the most efficient manner for other projects where he may be working for a fixed price. The cost plus project may tend to be a fill-in project for these resources at times when they cannot be more efficiently applied elsewhere.

Phased Construction or Fast-Track

These are terms used to describe a planning and construction procedure based on the concept of combining planning and construction activities in the same time frame. Construction is accomplished by means of separate bid packages or contracts and the work included in each package is designed and contracted for as it is required in the normal construction sequence. For example, a contract could be awarded for site preparation, excavating and grading as soon as the building configuration, location and basic structural requirements are determined. This work may be in progress as the design of other work required later in the construction sequence is being developed. The net effect is a shortening of the total time necessary for planning and construction.

Positive Aspects of Phased Construction

1. Allows construction to begin before the building design is completed resulting in a quicker finished product.

2. Many design decisions do not have to be made far in advance; therefore it is possible to postpone them or change them even while work is in progress. Advantage can be taken of the latest developments or revisions to the building's needs.

3. The owner can have more input into decisions because he can make many of them with the knowledge of seeing the actual design as it develops in construction.

4. Because the work is in bid packages each piece can be better scrutinized, trade-offs can be made before the fact rather than having to rework and rebid an entire project that does not meet the budget.

5. Many portions of the work can be placed under contract sooner resulting in lower costs in times of escalating prices.

6. Multi-bidding allows direct communication with each bidder, not through a general contractor. It is often possible to work out cost saving alternatives before a formal contract is signed.

7. Each contract can be bid at the time the work is needed. The bidder does not have to gamble on labor and material costs in the distant future. He will not have to pad his bid for possible future contingencies.

8. Long lead time equipment can be directly purchased by the owner early and then incorporated into the project as construction requires.

Negative Aspects of Phased Construction

1. Early decisions must be correct; they are difficult to change after the concrete is in place.

2. Total cost is not guaranteed at the beginning.

3. Construction begins before the design is finalized so the owner does not know exactly what the end product will be before work is commenced.

Design/Build or Turnkey Construction

These terms apply to a "package deal" method whereby there is one single financial transaction under which one firm agrees to design and construct a building to the specific order of an owner. As far as the owner is concerned there is but one responsibility and only one contract including all services and material necessary to the planning and construction of his proposed project.

The design/build organization may be selected by direct negotiation or by a conventional bidding process where bids submitted are based on the owner's detailed performance specifications of his well defined educational program.

Positive Aspects of Design/Build

1. Total cost for planning and construction is known at the beginning. There is a guaranteed maximum price known for the complete planning and building process before any funds are expended, even for planning.

2. Having one total responsibility allows early construction start and short completion time.

3. Complete management and coordination between architect and contractor, since they are the same firm.

4. Through the negotiation or bidding process the owner can get free ideas from the proposed schemes without commitment to any one.

5. Can relieve the owner of the need to select an architect inasmuch as his services are a part of the total package being bid or negotiated.

6. There seems to be some evidence that on the whole the design/build method is one of the lowest cost methods that can be employed.

Negative Aspects of Design/Build

1. Cost is known at the outset but what the owner will specifically get for his money is not known with any degree of precision because plans have not been completed, yet the owner has agreed to accept <u>any</u> plans that meet contract stipulations.

2. The package dealer utilizes architectural services so the services are there but the allegience is now to the builder, not the owner.

3. No opportunity for people in the community to have input into their building program in the planning stages through the architect. Specific community groups or teachers or students who want to be heard cannot be accommodated in the planning process as a requirement for bidders without running the cost up to cover what might be required to satisfy those groups.

4. The end product will satisfy only the stated requirements. If there is an unpredictable variety of needs as well as the known basic shelter needs the owner is not likely to get a solution that will accommodate them. The solutions will be the most economical way to provide for stated program requirements only.

5. The building cannot be described in terms of drawings and specifications until design and construction drawings are completed. This would of course defeat the purpose of the method. The bidding documents must describe the building in terms of performance standards. This is difficult to do completely and accurately.

Systems Building

The term "Systems Building" is used to describe such a variety of conditions that it has come to have a broad range of meanings. Any discussion concerning systems building, therefore, requires an understanding of the specific context in which the term is being applied.

Systems building as it first attained prominence in school plant implementation represented an approach to design and construction based on viewing a building as a collection of separate but compatible subsystems, each performing some necessary aspect of the building's function. For example, a building can be viewed as being composed of a structural system, enclosure system, environmental control system, illumination

system, and interior finish system. For constructing a building viewed in this manner, building bidders are asked to submit bids for all work and materials necessary to complete an entire subsystem regardless of the building trades or variety of materials that might be required. Requirements for each subsystem are based on performance specifications, that is, what must the subsystem do and how well must it do it, rather than on prescription requirements spelling out acceptable materials and methods of construction. The choice of materials and construction methods are left to the discretion of the bidder so long as they fulfill the performance standards set. The purpose of such an arrangement is an attempt to encourage bidders to propose new or better ways to accomplish a functional need. The well known S.C.S.D. projects in California and the F.S.S.P. projects in Florida were instances where this basic systems concept was employed.

As a result of the above and similar projects, industry has developed factory built components and assemblies that can be applied in much school construction. Today any building that is planned so as to utilize factory built components or pre-fabricated sub-assemblies is also often termed a systems building. Project requirements may be stated in terms of specific pre-engineered materials or components that will be acceptable rather than the performance requirements that must be fulfilled.

Any project based on the concept of dividing construction responsibility according to functional aspects rather than the materials

required or building that is designed around the concept of incorporating prefabricated factory components to a significant extent is also often referred to as a systems building.

Positive Aspects of Systems Building

1. Systems building furnishes a way to gain advantages of industrial mass production without the necessity for stock or packaged plans. Mass produced standard components may easily be arranged in a variety of ways to accommodate individual needs and desires.

2. On-site labor and construction time are minimized.

3. The systems method lends itself readily to time saving phased construction processes and the pre-purchasing of key elements.

4. Quality can normally be better controlled at the factory than at the job site.

5. Standard component systems increase the likelihood that future replacement of worn out systems will be easier.

6. Cost estimating in the early design phase should be more accurate for factory built components than for job-built one-of-a-kind designs.

Negative Aspects of the Systems Approach

1. If systems projects are based only on performance specifications as an attempt to develop new solutions to building problems the research required by bidders will entail extensive time and expense, so much so that bidders will have little interest unless the project presents the possibility of a very substantial market for the systems to be developed. This process is only practical for very large projects

and is not apt to save time.

2. The writing of performance specifications is not as yet a well developed art. A systems project or any approach that is based completely on performance specifications may encounter difficulties in insuring a desired result without also including the possibility of undesirable side effects. A proposed system may conform to the performance criteria established in every respect but it may also possess some undesirable aspects that could not have been forseen or which may not become apparent until some later date.

3. A systems approach that consists of employing "shelf-item" tried and true components, specified by prescriptive means, will overcome most of the negative aspects above, but any opportunity for realizing new or better solutions to the problems at hand will also be lost.

4. The most efficient use of any manufactured system requires that the system not be altered or subjected to special conditions. This results in some loss of freedom of design but normally is not significant to the basic building function or aesthetics when an imaginative designer is employed.

5. In systems building the system contractor or installer may in fact be the system manufacturer with headquarters in some distant city. Coordinating and scheduling the work of various systems contractors will require precise contract documents and expert management of the construction process.

Construction Management

"Construction Management," :"Construction Program Management" or other similar terms are used to describe an approach in which the owner retains for a fee a management firm whose duties may include services of the following nature:

1. Cost management - estimates, cost analysis, value engineering studies, etc.
2. Scheduling of pre-construction, construction, and post construction activities.
3. Consultation with the designing architect on current construction technology, market conditions and costs so as to insure that the project will be planned to fit the allowed budget. Design review to identify potential construction or coordination problems.
4. Determination of the most appropriate process for implementing construction, and advice to the architect in preparation of documents necessary to bidding and purchasing activities. Establishment of the optimum bid packages.
5. Assumption during construction of the duties traditionally performed by the general contractor in obtaining subcontractors, coordinating and scheduling their work, and in general supervising and managing the entire construction process acting as an agent of the owner. Provide on-site supervision, inspection and administration.

6. Preparation of cash flow schedules that will enable the owner to precisely plan financial needs during the life of the project.

There is no generally accepted list of standard or basic services furnished by all construction management firms. Some firms cannot effectively furnish all the services listed above and some firms have a capacity to provide an even wider range of services. Certain firms may have greater expertise in the programming and scheduling aspects while others may be strongest in the cost and construction aspects. Since there is such a broad range in the capabilities of construction management firms it is essential that the owner thoroughly understand his most essential needs before choosing a construction manager.

In its most productive application construction management eliminates the general contractor working for a profit, construction being accomplished instead through an agent of the owner working for a predetermined fixed fee. It also insures direct involvement between the project designer and its builder, even during the planning stages, and it provides for the owner overall management and administration of all project activities from inception to occupancy.

Factors affecting the cost for construction management services are many and varied making it impossible to precisely predict them for a specific project. As a general indicator, however, it appears that a list of services such as the ones enumerated above is presently commanding a fee approximating four percent of the project cost.

Positive Aspects of Construction Management

1. Construction management permits maximum freedom and flexibility to pursue any construction procedure. Systems building, phased construction, pre-purchase of materials or equipment, etc., are all easily accomplished when the owner has an in-house general contractor.

2. The classic adversary relationship that often develops between owner and builder in conventional construction is eliminated. The struggle by the owner to get the most for the contract price and the builder to do the least for the price need no longer develop as both parties have an equal incentive to get the best possible value for dollars spent.

3. More accurate cost estimating and tighter control of budget during planning and construction. The architect's cost estimates are verified by the construction manager during design. The construction manager's input into the design process assures there will be no great cost surprises when entering into the construction phase. Valuable time will not be lost in redesigning after bids that did not conform to the pre-bid estimate.

4. Competitive bidding or legal requirements for public bidding need not be eliminated. Contract bid packages can be publicly advertised and bid in accordance with any requirements for public purchase of goods or services.

5. The saving in time between realization of a need to the completion of the project is estimated at between six months and a year, depending on the nature and scope of the project. In times of rising prices such as we have experienced in recent years this time saving alone should result in cost savings that equal or exceed the fee of the construction manager.

Negative Aspects of Construction Management

Assuming a wise choice of construction managers, the only obvious negative aspect of the construction management approach is the absence of a guaranteed fixed building cost at the time construction is begun. This condition can be overcome by some construction management firms who offer the option of furnishing a guaranteed maximum building cost at the completion of the preliminary design. Such an arrangement preserves the construction manager's input into the design and preliminary estimate phase of construction, but the fact of his direct financial involvement in the construction causes his relationship with the owner to revert more nearly to that of conventional general contractor during this phase of the project.

A compromise between having a guaranteed fixed cost on the one hand or a construction manager whose complete loyalty is to the owner's best interests on the other hand can be approached by a method requiring that early sub-contract bids for a sizeable portion or the project be finalized before construction is begun. This can be accomplished with minimal loss of project completion time and will in effect guarantee the cost for a large portion of the project. An evaluation of the early bid results can furnish a go or no go check point for the project. If early bids fit reasonably the projected budget there is little doubt that the flexibility possible with the construction manager approach enables adjustment of contract requirements (should it become necessary) to achieve a completed facility within the budgeted amount. The probability for a budget overrun that cannot be avoided is no greater than the chances of encountering an unexpected necessary contingency

item in a conventional lump sun contract situation. A further assurance against such a possibility is the previous performance record of the construction management firm selected.

BUILDING IMPLEMENTATION OPTIONS

One of the first decisions which must be made by the owner in beginning to implement any building program involves selecting the basic path to be followed in planning and construction. There are at least three essentially different options that may be followed, each with several variations.

Conventional Architect/Builder Method

Under this option the owner selects through a process of negotiation, an architect who will plan, prepare contract documents for, and supervise construction of the needed facilities. When the design and contract documents have been completed a publicly advertised process of competitive bidding is undertaken to select a general contractor who agrees to complete the entire construction for a lump sum fixed amount. This is a very abbreviated description of the basic implementation process that has been standard practice for many years and that which is described under "Lump Sum - Single Contract." It is also the most costly method in terms of time and money in most instances.

Variations to this basic procedure may include dividing the work into a series of separate contracts as discussed under "Lump Sum - Separate Contracts." This variation offers some opportunities for reduced cost and possible time savings.

Another possibility is the selection of a builder through the process described under "Direct Negotiation". This variation does not have the advantage of a guaranteed known cost before construction is begun. It is usually a more economical way to proceed in renovating or remodeling work where costs are difficult

to determine in advance, or where certain program requirements may not be set when construction begins, or where many changes are anticipated during construction.

Procedures discussed under "Phased Construction" and "Systems Building" are additional devices that may be incorporated within the framework of the architect/builder method.

An owner who wishes to consider any variation to the conventional lump sum single contract method should discuss the feasibility of the variations for the project in hand with prospective architects during the negotiations stage. Architects may require a larger fee to cover added work that may be necessary. A final decision to undertake variations often is not practical until planning has begun but where the eventual possibility exists the amount of any fee adjustments required should be made a part of the architectural service negotiations and incorporated into the owner-architect agreement so as to avoid possible future misunderstanding.

<u>The "Package Deal" Approach</u>

Under this option the owner elects to purchase a combined planning and construction package as discussed under "Design/Build or Turnkey Construction." The method has an appeal of simplicity to owners in that there is a known guaranteed cost, only one contract, and the promise for rapid realization of a completed facility once the design/build team is selected. As with many things that seem simple on the surface it has on closer inspection the possibility for many complications.

An owner who opts to go design/build should be certain that he can adequately state complete facility requirements in his bidding or negotiating documents as changes in program requirements

once a contract is signed are apt to be very costly. The owner should also have expertise in building matters that will enable him to: evaluate design proposals in the light of his program requirements; supervise construction so as to verify that agreed upon design intentions are being carried out in the building; and check actual construction progress against progress payment requests so as to be certain that he has actually received that which he is being asked to pay for. He needs in effect the expertise of a top notch facilities programmer and supervising architect or engineer. Expert legal counsel in building matters must also be available.

The selection of a design/build team to plan and construct a facility may be made through (1) a process of inviting prospective candidates to submit preliminary design and cost estimate proposals for consideration and then subsequent nogotiation with the most promising candidate or (2) the selection may be made through a conventional public bidding process where binding bid proposals are solicated from interested candidates based on owner stated performance requirements.

To detail performance requirements for any but the very simplest of functions in a way that eliminates possible undesirable design results is an even more formidable task than the preparation of performance specifications for building systems. The first alternative provides more owner control over the final outcome but may raise criticism that free competitive bidding practices are being violated.

The least troublesome and perhaps most appropriate application of the design/build method is one in which the owner needs a simple

facility fast and determines that the need can best be filled by a facility similar to one already in existence. In this situation program requirements are written using the existing facility as a guide to serve as a full scale model or standard for design and construction requirements as well. An example might be where school district A determines a pressing need that can best be filled by a new elementary facility similar to one already in existence in district B with only slight planning or construction modifications and necessary site adaptations. Programming and checking for compliance with design and construction intent will be greatly simplified in this instance but the need for construction supervision and legal counsel will be altered very little.

Construction Management Option

This method combines the efforts of owner, architect, and construction manager in a team approach. Both architect and construction management consultant are selected and retained by the owner before serious facility planning is undertaken. The architect assumes responsibility for the traditional planning and design services and the construction management firm is responsible for implementation of construction and other services discussed under "Construction Management" that may be desired.

A decision to employ the architect - construction manager approach is best made before an architect is selected. Prospective candidates for architectural services should be aware of the owner's intent before they are asked to submit tentative fee proposals. Experience has shown that architectural firms may reduce their fee when construction management firms are to be engaged.

A construction management firm may be selected in the same manner that the architect is chosen, through the soliciting of preliminary proposals and subsequent negotiation with the most promising prospect. The process may precede, be concurrent with or follow the selection of the architect, but when negotiations for architectural and construction management services are conducted at the same time possible unwanted duplication of services or misunderstanding concerning what services are the responsibility of which consultant may be avoided. Best results will only be obtained when the firms selected work harmoniously as a team, so it will be advantageous for the owner to obtain the reactions of prospective architects and construction managers, each to the other, before making a commitment to either, as a means to further insure compatibility.

Due to the wide scope of services that are classified under the broad heading of construction management and because there is at present no formal licensing or professional regulation of standards governing the qualifications of construction management firms as such, great care must be exercised in making a choice if satisfactory results are to be expected. In reviewing prospective firms a proven track record including many satisfactorily completed projects, constructed according to schedule and within preliminary cost projections is a primary indicator of a firm's capabilities.

There is no uniformly accepted minimum project size for which the construction management approach is warranted. The potential benefits of the system appear so promising that none but the simplest of projects should be anticipated without at least exploring the feasibility of the method. Projects that may individually be

too small to attract capable construction management services may do so if they can be assembled into groups of projects which collectively are large enough to be attractive. A school district for example could decide that an entire building program within the district will be implemented through one construction management firm even though several architects are involved.

SUMMARY GUIDELINES

- Systems building and phased construction techniques are time saving procedures. Savings in time almost always result in lower costs therefore incorporation of one or both of these techniques should be seriously considered regardless of the implementation option selected.

- When a school district has a project or group of concurrent projects having an estimated value in excess of $1,000,000, very serious consideration should be given to the construction management option - even if several architects are involved.

- If construction cost must be known before construction can begin the possible implementation options are limited to:

  1. Conventional architect/builder (single or separate contracts)
  2. Package deal approach
  3. Construction management with a guaranteed maximum.

- If a project is primarily remodeling and renovating or minor additions, best results will usually be obtained through a negotiated contract - cost plus fixed fee or cost plus including a guaranteed maximum are preferred fee arrangements.

- Where a facility is to be a duplication or near duplication of an existing facility the options appropriate include:

  1. Conventional architect/builder (single or separate contracts)
  2. Design/build or package deal
  3. Construction management.

Design build will probably achieve the fastest delivery but construction management will provide better owner control.

- Projects on which community staff or faculty input is desired or where innovative planning or design concepts are sought are apt to be most successful if the implementation method is either the conventional architect/builder method or the construction management option when project size warrants.

- The design/build option should be considered only if the owner has at his disposal personnel who can evaluate conformance of drawings and specifications to performance requirements, verify construction conformance to contract requirements and certify accuracy of contractor payment requests.

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- Mr. William A. Nassal, Contract Engineer, Turner Construction Company, Cleveland, Ohio

BUILDING PROGRAM SEQUENCE AND RESPONSIBILITY CHART
CONVENTIONAL ARCHITECT - BUILDER METHOD (LUMP SUM - SINGLE CONTRACT)

STEP	OWNER - LOCAL BOARD OF EDUCATION	ARCHITECT	OFFICE OF EDUCATIONAL FACILITIES CONSTRUCTION - STATE DEPT. OF EDUCATION	CONTRACTOR
1	SELECT CONSTRUCTION PROCEDURE AND FILE WITH STATE OFFICE SEE 6A-2.11(4) (5)			
2	SELECT ARCHITECT SEE 6A-2.04			
3	PREPARE EDUCATIONAL SPECIFICATIONS SEE 6A-2.10	PREPARE PHASE I SCHEMATIC DOCUMENTS SEE 6A-2.13		
4	SUBMIT PHASE I DOCUMENTS & ED. SPECS. TO STATE OFFICE			
5			APPROVE OR RECYCLE PHASE I SCHEMATICS & EDUCATIONAL SPECIFICATIONS	
6	PREPARE PHASE II DOCUMENTS SEE 6A-2.14	PREPARE PHASE II DOCUMENTS SEE 6A-2.14		
7	APPROVE PHASE II DOCUMENTS & SUBMIT TO STATE OFFICE			
8			APPROVE OR RECYCLE PHASE II DOCUMENTS	
9		PREPARE PHASE III DOCUMENTS SEE 6A-2.15		
10	SUBMIT PHASE III DOCUMENTS TO STATE OFFICE. SEE 6A-2.15			
11			APPROVE OR RECYCLE PHASE III DOCUMENTS	
12	ADVERTISE FOR, ACCEPT BIDS, AWARD CONTRACTS SEE 6A-2.16 & 6A-2.23	ASSIST OWNER IN TAKING AND EVALUATING BIDS		SUBMIT CONSTRUCTION BID
13				SUBMIT EXECUTED BONDS, INSURANCE CERTIFICATES, LIST OF SUB-CONTRACTORS MATERIAL SUPPLIERS. SEE 6A-2.15
14	AUTHORIZE CONTRACTOR TO PROCEED WITH CONSTRUCTION SEE 6A-2.15/A.			SUBMIT BREAKDOWN OF COSTS
15	SUBMIT CONTRACTOR'S COST BREAKDOWN TO STATE OFFICE SEE 6A-2.18			BEGIN CONSTRUCTION
16				SUBMIT PERIODIC PAYMENT REQUESTS TO OWNER THROUGH ARCHITECT
17		CERTIFY CORRECTNESS OF CONTRACTOR PAYMENT REQUESTS TO OWNER		
18	ISSUE PAYMENTS TO CONTRACTOR ON ARCHITECT'S CERTIFICATION SEE 6A-2.19			
19				NOTIFY ARCHITECT THAT WORK IS SUBSTANTIALLY COMPLETE
20		INSPECT WORK, ISSUE LIST OF UNCOMPLETED OR UNSATISFACTORY WORK		
21				NOTIFY ARCHITECT OF FINAL COMPLETION
22		INSPECT WORK, CERTIFY TO OWNER THAT PROJECT IS COMPLETE		
23	ACCEPT COMPLETED PROJECT & REQUEST STATE OFFICE FINAL INSPECTION SEE 6A-2.24			
24			INSPECT COMPLETED WORK AND ISSUE CERTIFICATE OF FINAL INSPECTION	
25	RELEASE FINAL PAYMENT TO CONTRACTOR			
26	OCCUPY FACILITY ON DATE INDICATED ON CERTIFICATE OF FINAL INSPECTION			

BUILDING PROGRAM SEQUENCE AND RESPONSIBILITY CHART
PACKAGE DEAL - DESIGN / BUILD OR TURNKEY METHOD

Step	OWNER - LOCAL BOARD OF EDUCATION	DESIGN/BUILD CONTRACTOR	OFFICE OF EDUCATIONAL FACILITIES CONSTRUCTION - STATE DEPARTMENT OF EDUCATION
1	SELECT CONSTRUCTION PROCEDURE AND FILE WITH STATE OFFICE. SEE 6A-2.11(4)(5)		
2	PREPARE EDUCATIONAL SPECS. (6A-2.10) AND FACILITY PERFORMANCE CRITERIA		
3			APPROVE OR RECYCLE EDUCATIONAL SPECS. AND PERFORMANCE CRITERIA
4	ADVERTISE FOR, ACCEPT PROPOSALS AND EVALUATE DESIGN CONCEPT BIDS	SUBMIT DESIGN CONCEPT PROPOSALS BASED ON ED. SPECS. AND PERFORMANCE CRITERIA	
5	SUBMIT ACCEPTABLE DESIGN CONCEPT BIDS TO STATE OFFICE		
6			APPROVE ALL ACCEPTABLE DESIGN CONCEPT BIDS
7	ACCEPT BIDS FROM ACCEPTABLE DESIGN CONCEPT BIDDERS FOR DETAILED PLANNING AND CONSTRUCTION OF FACILITY		
8	EVALUATE BIDS AND AWARD CONTRACT FOR DESIGN AND BUILD SERVICES		
9		PREPARE DETAILED PLANS & SPECS FOR APPROVAL OF COMPLIANCE WITH CONTRACT INTENT (ENTIRE PROJECT OR PHASES AS REQUIRED)	
10	APPROVE DETAILED PLANS & SPECS. SUBMIT TO STATE OFFICE FOR APPROVAL		
11			APPROVE OR RECYCLE DETAILED PLANS AND SPECIFICATIONS
12	PROVIDE FOR CONSTRUCTION INSPECTOR SEE 6A-2.23	SUBMIT EXECUTED BONDS, INSURANCE CERTIFICATES, LIST OF SUB-CONTRACTORS AND MATERIAL SUPPLIERS. SEE 6A-2.15	
13	AUTHORIZE CONTRACTOR TO PROCEED WITH CONSTRUCTION	SUBMIT BREAKDOWN OF COSTS	
14	SUBMIT CONTRACTOR'S COST BREAKDOWN TO STATE OFFICE. SEE 6A-2.18	BEGIN CONSTRUCTION	
15		SUBMIT PERIODIC PAYMENT REQUESTS TO OWNER	
16	VERIFY CORRECTNESS & ISSUE PAYMENTS TO CONTRACTOR. SEE 6A-2.19		
17		NOTIFY OWNER THAT WORK IS SUBSTANTIALLY COMPLETE	
18	INSPECT WORK, ISSUE LIST OF UNCOMPLETED OR UNSATISFACTORY WORK		
19		NOTIFY OWNER WHEN WORK IS FINALLY COMPLETE	
20	INSPECT & ACCEPT COMPLETED PROJECT. REQUEST STATE OFFICE FINAL INSPECTION. SEE 6A-2.26		
21			INSPECT COMPLETED WORK & ISSUE CERTIFICATE OF FINAL INSPECTION
22	RELEASE FINAL PAYMENT TO CONTRACTOR		
23	OCCUPY FACILITY ON DATE INDICATED ON CERTIFICATE OF FINAL INSPECTION		

BUILDING PROGRAM SEQUENCE AND RESPONSIBILITY CHART
CONSTRUCTION MANAGEMENT METHOD (PHASED CONSTRUCTION)

Step	OWNER - LOCAL BOARD OF EDUCATION	CONSTRUCTION MANAGEMENT FIRM	ARCHITECT	OFFICE OF EDUCATIONAL FACILITIES CONSTRUCTION STATE DEPT. OF EDUCATION	PRIME PHASE CONTRACTORS
1	SELECT CONSTRUCTION PROCEDURE AND FILE WITH STATE OFFICE SEE 6A-2.11(4)(5)				
2	SELECT ARCHITECT AND CONSTRUCTION MANAGER SEE 6A-2.04				
3	PREPARE EDUCATIONAL SPECIFICATIONS SEE 6A-2.10	ASSIST PREPARATION PHASE I SCHEMATICS	PREPARE PHASE I SCHEMATIC DOCUMENTS SEE 6A-2.13		
4	SUBMIT PHASE I DOCUMENTS AND ED. SPECS TO STATE OFFICE				
5				APPROVE OR RECYCLE PHASE I DOCUMENTS AND EDUCATIONAL SPECS.	
6	PREPARE PHASE II DOCUMENTS. SEE 6A-2.14	ASSIST PREPARATION OF PHASE II DOCUMENTS	PREPARE PHASE II DOCUMENTS. SEE 6A-2.14		
7	APPROVE PHASE II DOCUMENTS & SUBMIT TO STATE OFFICE				
8				APPROVE OR RECYCLE PHASE II DOCUMENTS	
9		DETERMINE OPTIMUM NUMBER, SEQUENCES & CONTENT OF BID PACKAGES.			
10		PREPARE PHASE III DOCUMENTS FOR INITIAL PACKAGES. 6A-2.15	PREPARE PHASE III DOCUMENTS FOR INITIAL PACKAGES. SEE 6A-2.15		
11	SUBMIT PHASE III DOCUMENTS FOR INITIAL BID PACKAGES TO STATE OFFICE				
12				APPROVE OR RECYCLE PHASE III DOCUMENTS FOR INITIAL BID PACKAGES	
13	ADVERTISE, ACCEPT BIDS, AWARD CONTRACTS. SEE 6A-2.16	ASSIST OWNER IN TAKING & EVALUATING BIDS			SUBMIT EARLY BID PACKAGE PROPOSALS
14					SUBMIT BONDS, INSURANCE CERTIFICATES, SUB-CONTRACTOR LISTS
15	AUTHORIZE CONTRACTORS TO PROCEED WITH CONSTRUCTION. 6A-2.15/4				SUBMIT BREAKDOWN OF COSTS THROUGH C.M. TO OWNER
16	SUBMIT CONTRACTOR'S COST BREAKDOWNS TO STATE OFFICE. 6A-2.18				BEGIN CONSTRUCTION
17		ADMINISTER AND SUPERVISE CONSTRUCTION CONTRACTS	PREPARE (WITH C.M. ASSISTANCE) BALANCE OF PHASE III DOCUMENTS AS REQUIRED.		
18	SUBMIT PHASE III DOCUMENTS FOR SUBSEQUENT BID PACKAGES TO STATE OFFICE AS THEY ARE DEVELOPED			APPROVE OR RECYCLE SUBSEQUENT PHASE III DOCUMENTS AS SUBMITTED	
19	ADVERTISE, ACCEPT BIDS, AWARD CONTRACTS FOR SUBSEQUENT BID PACKAGES	ASSIST OWNER IN TAKING & EVALUATING SUBSEQUENT BIDS			SUCCESSFUL BIDDERS SUBMIT BONDS, INSURANCE CERTIFICATES, SUB-CONTRACTORS LISTS AS REQUIRED
20	AUTHORIZE SUBSEQUENT CONTRACTORS TO PROCEED WITH CONSTRUCTION				SUBMIT SUBSEQUENT CONTRACTOR'S COST BREAKDOWNS THROUGH C.M. TO OWNER
21	SUBMIT SUBSEQUENT CONTRACTOR'S BREAKDOWNS TO STATE OFFICE	ADMINISTER AND SUPERVISE ALL CONSTRUCTION CONTRACTS			BEGIN CONSTRUCTION ON SUBSEQUENT CONTRACTS AS REQUIRED
22					EACH PRIME CONTRACTOR SUBMITS PERIODIC PAYMENT REQUEST TO OWNER THROUGH C.M.
23		CERTIFY CORRECTNESS OF ALL PAYMENT REQUESTS TO OWNER			
24	ISSUE PAYMENTS TO CONTRACTORS ON ARCHITECT'S CERTIFICATION. SEE 6A-2.19				
25					NOTIFY C.M. WHEN CONTRACT WORK SUBSTANTIALLY COMPLETE
26		INSPECT COMPLETED WORK. CERTIFY TO OWNER THAT CONTRACT HAS BEEN COMPLETED			
27	ACCEPT COMPLETED CONTRACT. REQUEST STATE OFFICE FINAL INSPECTION 6A-2.24				
28				INSPECT COMPLETED WORK. ISSUE CERTIFICATE OF FINAL INSPECTION	
29	RELEASE FINAL PAYMENT TO CONTRACTOR				
30	OCCUPY FACILITY ON DATE INDICATED ON LAST CERTIFICATE OF FINAL INSPECTION.				

ANALYSES AND RECOMMENDATIONS

RELATED TO PUBLIC SCHOOL CONSTRUCTION

Section V - A PLAN FOR UTILIZING SOLAR ENERGY IN STATE SCHOOLS

PLAN FOR DEVELOPMENT OF SOLAR ENERGY UTILIZATION IN FLORIDA SCHOOLS

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INTRODUCTION

The impending shortage of fossil fuels leading to subsequent shortages of power and electricity has already been alluded to in prior sections. Current estimates indicate that the demand for energy in the forseeable future will grow at the rate of about 4.2 percent per year. At the same time energy supplies, including anticipated sources such as the Alaskan North Slope, will grow at a rate of only about 2.6 percent per year. It is estimated that energy utilization in housing alone accounts for about 22 percent of the total annual energy consumption in the United States. In terms of building types, educational facilities rank second only to housing in building volume, therefore represent a major source of energy consumption.

One of the potential alternatives to the energy shortage is the utilization of solar energy for the purposes of heating water and conditioning buildings. Basically, utilization of solar energy involves (1) a device for collecting the direct and/or diffuse energy from the sun; (2) a method of storing the solar energy collected; and (3) utilization of the stored energy either directly (in the case of hot water) or indirectly where some conversion of the stored energy may be required for heating and cooling of building spaces.

It is beyond the scope of this report to discuss at length the many ramifications of solar energy application; however, a brief review is included to establish the basis for recommendations.

STATE OF THE ART

Water Heating

Solar energy can now be used to provide most of the hot water required for all purposes except for space heating, at a first cost that some have estimated will be returned in a period as short as three to five years. The Solar Energy Center at Cape Canaveral has been given as one of its first assignments the development of design criteria for such systems. Many domestic systems employing solar energy as a heat source are now being used in Florida. No information has been found which indicates how much energy is being used for heating water in Florida schools; however, a New York City study indicates that about 6 percent of the school energy budget went for that purpose.

The most common type of system for water heating is a flat plate collector with a large well insulated storage tank and small circulating pump, with automatic controls to regulate flow through the system. Some guidance is presently available on the best type of collector to use, size required, and best orientation. More precise criteria is now being developed and should soon be available.

Space Heating

Solar energy can now be used to greatly reduce the energy required for space heating. The Federal Government, under ERDA, now has a program under way for the development and testing of both components and complete systems. For space heating the same type of flat plate

collector is generally used; however, a much larger collector area is required, together with a larger storage tank. Proper insulation and controls are of prime importance.

Space Cooling

Solar energy is now being used to a very limited extent for space cooling. It is generally estimated that it will be at least ten years before such applications become economically feasible. Present systems are very costly compared with conventional cooling systems. As with space heating, there are a number of experimental systems now in service which are producing data upon which the practicality of this type of system can be based. Most of these systems are "water fired" lithium bromide systems, with solar energy being supplemented with other heat sources to provide the heat required.

For space cooling the same collector as employed for heating can be used to supply heat to a lithium bromide absorption type refrigeration system. Present information indicates that this heat will generally not be sufficient to operate the system by itself, and supplemental heat from conventional sources will be required. A great reduction in energy requirement from conventional sources will, however, be achieved.

CONSTRAINTS ON SOLAR ENERGY UTILIZATION

Technical Constraints

The present network of solar radiation collection stations is generally inadequate; data errors are presently estimated to range

from ± 5% to ± 30%.

There are inadequate data on solar equipment components and materials performance.

There are inadequate design criteria available on collectors, storage units, heat transfer and operational controls.

There are inadequate standards for measurement of performance and evaluation of systems.

A basic problem in all solar systems is the storage of energy to take care of periods when there is little or no sunshine. No satisfactory method for long time storage has yet been developed. Until there is, it appears that either full capacity standby equipment will be necessary or a facility would have to shut down during extended cold periods.

Institutional Constraints

Despite a great deal of lip service paid to the potential of solar energy by federal and state governments during the past four years, there has been relatively little real commitment. Solar technology is probably more advanced than any of the other potential energy sources; actual funding of research and development has lagged far behind other energy R and D programs.

There are a number of legal issues that have yet to receive any substantial attention; these include sun rights, zoning and building codes.

There is considerable confusion about the relationship of utility companies to the solar energy field.

Long promised "breaks" in the form of subsidies, reduced taxes, etc., have not materialized in any substantial fashion. Additionally, lending agencies have thus far resisted the idea of increasing "front end" money to underwrite long-term savings for the owner.

Industry Constraints

The most critical constraint is the lack of an assured market. Manufacturers are understandably reluctant to make large capital investments until there is a clear demand for their products.

No clearly defined, substantial solar industry has yet appeared within the building industry.

There is much concern within the industry over many of the constraints mentioned previously - the lack of reliable data, absence of controlled performance standards and inadequate financing combine to limit Industry's R and D activity as well as its production capacity.

POSITIVE ASPECTS OF SOLAR ENERGY UTILIZATION

Despite all of the foregoing negative aspects, solar energy may well be the best alternative energy source available in the near future. (1) It is a non-depletable source of energy. (2) Because of its diffuse nature it is universally available. This means that it can be collected, stored and used at the same location where it is needed. (3) There is no major loss in efficiency due to transmission, as in our present systems. (4) It is considered a 'clean' - that is, a non-polluting source.

While dramatic technical break-throughs should not be assumed, there are encouraging signs of improving technology in the solar energy field. For example, solar energy is now being used with some success in improving the performance of heat pumps; Owens-Corning has developed an evacuated glass tube collector that promises much higher efficiency, etc.

There are signs that both government and industry, after several years of sparring, are at long last 'gearing up' to address the constraints previously mentioned. Many of the answers in the areas of criteria and standards, for example, will become available in the next one to five years.

RECOMMENDATIONS

1. Based on the foregoing discussion, it is recommended that the Office of Educational Facilities recognize solar energy applications as being in the experimental stage. Because of the critical need to conserve energy, every effort should be made to procure funding for R and D or demonstration projects. The term "demonstration" refers here to field applications, monitoring and observation.

2. It is recommended that life-cycle cost analysis techniques be applied to selected projects in the design stage. This will involve the design of solar energy system(s) then a comparison with the conventional system performing the same function.

It is further recommended such studies be performed periodically because of the rapid change in products and prices associated with solar equipment and systems.

At such time as life-cycle cost benefit analyses indicate solar systems are competitive with conventional systems, solar-designed systems should be required as one of the alternatives for consideration.

3. If R and D or demonstration funds are available and are not earmarked for a particular type of study, it is recommended that the funds be used on a priority basis, with water heating the first priority, space heating the second and space cooling the third.

4. It is recommended that a limited number of relocatable units be used as solar energy demonstration units with built-in monitoring and observation. It is believed this can be accomplished by adapting a ceiling-roof component without modification of standard components. In other words, this would not negate the existing component system; it would simply add a component to those already developed. (Refer to VI, Recommendations for Future Studies).

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ANALYSES AND RECOMMENDATIONS

RELATED TO PUBLIC SCHOOL CONSTRUCTION

Section VI - RECOMMENDATIONS FOR FUTURE STUDIES

RECOMMENDATIONS FOR FUTURE STUDIES

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INTRODUCTION

There was no request to include recommendations for future studies in this report; however, the limited period of the study combined with the broad scope of subject matter makes clear the need for follow-up study and research.

No attempt is made here to develop detailed recommendations; rather the listings and brief discussions are intended as suggestions that will lead to further discussions and projects.

At the risk of 'sermonizing' slightly, it is difficult to understand the lack of properly funded ongoing research that should take place in a program of the magnitude of educational facilities for Florida.

In dollar terms alone, for example, a slight increase in operating efficiency of just one item such as lighting would pay dividends far exceeding the most liberally supported research effort. Probably the energy crisis more than any other recent event has shown the weakness in the present approach to decision making in building. Traditionally we have relied on national codes that only incidentally take into account climate, resources and local practices. Almost total reliance for research information and ultimately standards is placed on industry. Understandably, it is virtually impossible for these organizations to make objective, non-prejudiced recommendations that might well reduce or eliminate their product. If the interests of the public are to be

served properly in the very expensive business of education, it seems essential that every effort be made to find the best possible answers, not rely on second-hand information.

Whether such research effort is produced directly by the Department of Education or 'farmed out', it is hoped that proper recognition of this need is forthcoming.

DESIGN CRITERIA AND ENERGY CONSERVATION

1. It is recommended that continuing research of energy conservation and related design be carried on by utilizing full scale building elements as test vehicles. These might be experimental structures or occupied school buildings depending on the type of study being conducted.

Some of the principal subjects that can be studied effectively in this manner include:

Thermal

Lighting and Electrical

Sound.

Proposed design criteria and standards can be evaluated on the basis of performance and energy efficiency. Such studies can provide valuable supplementary information to the traditional laboratory test of a single item, in that performance is evaluated in combination with other elements. Where studies can be conducted in occupied spaces, there is the added advantage of observing and documenting human response.

Many of the recommendations related to HVAC listed in Section I would lend themselves to this kind of program. There is also much to be gained from evaluating various trade-offs and combinations of artificial illumination and natural lighting. Selective instrumentation and monitoring of energy use in a limited number of facilities could also provide valuable insights to conserving energy.

2. Several subjects related to school building requirements were touched on only briefly or omitted and need additional study. These include electrical requirements related to materials, criteria for fixture selection and hazards. Related also to this category are the subjects of alarm systems, fire safety and emergency back-up systems.

It is believed that review and development of recommendations in these areas could then be supplemented by field testing and observation as previously described.

LIFE CYCLE COSTS

It is recommended that further studies be carried out in the following areas:

1. Determine the specific data that can realistically be collected in the areas of:

(1) Initial Building Cost

(2) Operation and Maintenance Cost

(3) Renewal Cost

(4) Life Spans of HVAC Systems

(5) Life Spans of Selected Building Material

This information should be available for each school district.

2. Design of the format for the collection of the above data.

3. Design of the proper format for architects and engineers to follow when presenting life cycle cost-benefit studies to local school boards.

4. Develop a detailed procedure to be followed when requiring life cycle cost-benefit studies for school facilities.

5. Determine the cost of preparing life cycle cost-benefit studies with the objective of establishing an appropriate fee.

6. Prepare a Life Cycle Cost-Benefit Manual for school officials.

7. Determine a life cycle cost-benefit system that would allow adequate tradeoffs for the beneficial effects of the utilization of solar heat gain, nocturnal cooling, natural ventilation, or direct utilization of daylight.

REGULATIONS, CHAPTER 6A-2

1. It is recommended that a study of 6A-2 be made comparing its relationship to other codes as to purpose, content and organization. It is assumed that particular attention would be given to the (Southern) Standard Code and the proposed State Building Code.

2. Attempts should be made to identify and isolate those requirements that may be peculiar to school construction as opposed to other building types.

3. There should also be a clarification of the relationship of special requirements or standards (such as 90-75) developed for controlling energy utilization to basic codes designed to protect the 'health, safety and welfare' of the public.

BID/BUILD PROCEDURES

1. All aspects of the construction management method should be thoroughly investigated. It is believed this process offers great potential for improving quality, speed and economy of construction.

2. Firms offering construction management services are not as yet licensed or professionally controlled in the dispensing of these specific services. There is a wide variation in the experience and capabilities of such firms. Guidelines for the prequalification and selection of these consultants should be developed to insure that only capable and responsible people will be employed to provide these services.

SOLAR ENERGY UTILIZATION

1. Proposed future studies have already been outlined in Section V of this report. One aspect not mentioned in that section is the need to provide assistance to individual school districts interested in solar energy but without adequate resources for developing proposals, locating funding sources, etc. Undoubtedly the larger school districts can accomplish this activity on their own (apparently one of the South Florida districts has already been funded by ERDA); it is believed that utilizing relocatable units for solar studies would provide smaller districts the opportunity to observe and gain experience in this area.

Date Due

Due	Returned	Due	Returned
	SEP 04 1992		
FEB 08 2001	FEB 23 2001		
MAR 16 2001	MAR 30 2001		